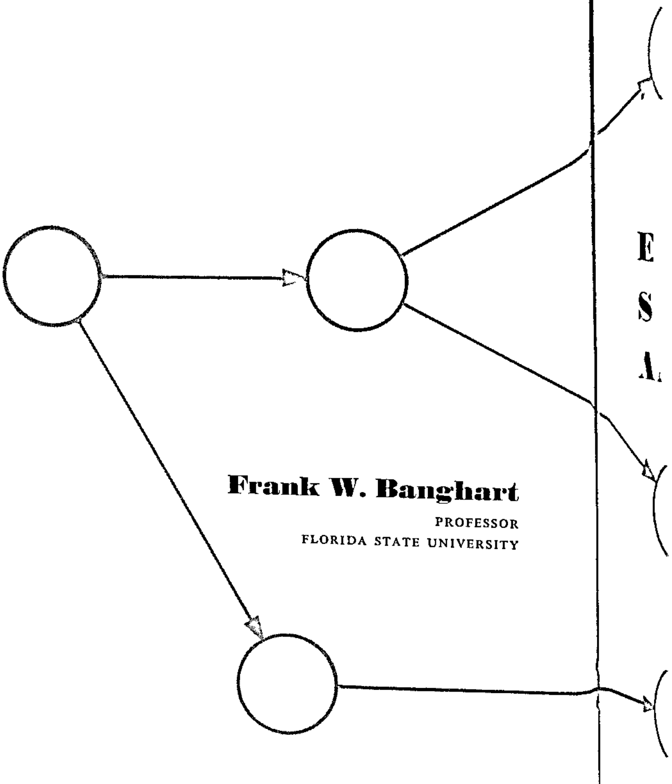
Educational Systems Analysis



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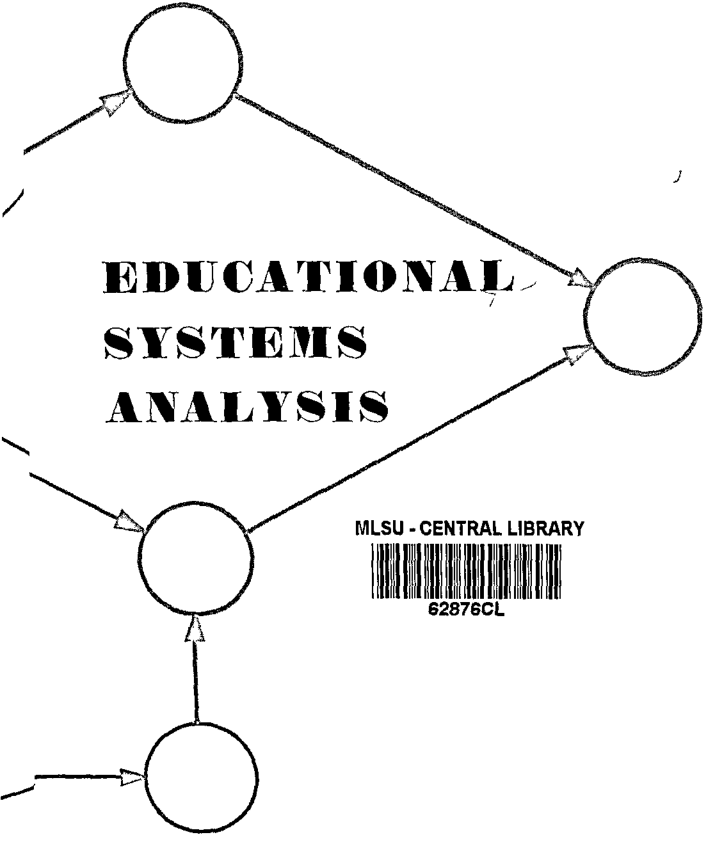

EDUCATIONAL SYSTEMS ANALYSIS

THE MACMILLAN COMPANY
COLLIER-MACMILLAN LIMITED, LONDON

First Printing

Library of Congress catalog card number 69 10314

THE MACMILLAN COMPANY
COLLIER MACMILLAN CANADA, LTD , TORONTO, ONTARIO

Printed in the United States of America

Preface

Since World War II a new management technology has emerged that has profoundly influenced management decision making in business, industry, government, and the military This new technology is known by many names One term that has gained reasonable standardization is *systems analysis* During the last few years educational administrators have become sensitized to the potential of the new systems technology in educational operations

Systems technology brings to educational management a scientific-quantitative approach for solving complex educational administrative problems

The purpose of this book is to furnish educational administrators (in practice and in preparation programs) with an orientation to systems technique and applications, in order that the field of education might benefit more fully from a technology which has been clearly helpful to management in general

Although systems technology is heavily quantitative, an attempt has been made in this book to offer the nonmathematically oriented administrator a sufficient introduction to the field of systems and its educational applications and implications

It is impossible, of course, to write a book on systems without including a certain amount of mathematics Systems technology is based essentially upon mathematics However, I have attempted to strike a balance between the two extremes of methodology and description

found useful. Chapter 8 reviews the work on simulation; Chapter 9 covers basic statistical designs; Chapter 10 illustrates in detail one basic technique for allocating resources.

I hope that this brief overview of the plan of the book will furnish the reader with a preview of the nature of systems procedures and applications.

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Acknowledgment

Special gratitude is expressed to Norma Lou Tomberlin for her major contribution to this book

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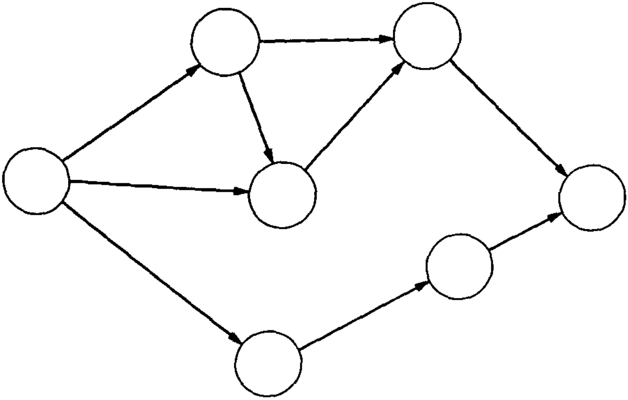
PART **ONE**

BACKGROUND OF SYSTEMS



CHAPTER 1

Introduction

The field of educational administration is becoming concerned with the set of quantitative-scientific techniques that assists the educational administrator in the decision-making process. These techniques are customarily referred to under the term *systems analysis*. Although the concept of systems analysis implies an investigation of a total system, the term denotes a set of quantitative-scientific tools available for analytical purposes. Specifically, some techniques associated with systems analysis include Program Evaluation and Review Technique (PERT) or Critical Path Method (CPM), linear programming, cost-utility analysis, and simulation.

Network analysis procedures furnish management with an administrative control over time and cost. Management can simulate a project in advance of the actual running of activities and permit continuous monitoring of time and cost factors after the activities have begun.

Linear programming, a mathematical tool for optimally allocating resources, was originally designed to handle a transportation problem. Assume that a number of ships are available at specific ports and that material requirements are needed at certain destinations. The linear programming model optimizes the number of shipments between origins and destinations.

Cost benefiting associates certain benefits or utilities derived from given activities with the costs associated with each activity. For example, if one

must make a decision about putting $20,000 into the special educational program, one needs to consider the payoff or utility of each program

Driver education does not have the same dramatic appeal as does special education Therefore, an administrator needs a different kind of evidence to support whatever decision is made A student who has taken a formal driver education course has a certain probability of being killed in an automobile accident The student who has not taken the course also has a probability of being killed in an automobile accident, and these two numbers are different They are different enough so that insurance companies give better rates to students who have completed the formal driver training course

To pursue this a bit further, the normal student has a certain expected economic return associated with his income potential The retarded youngster receiving benefits from special education also has an expected income or economic return Again these two numbers are different No one would advocate making the decision regarding putting the $20,000 into driver education or special education solely on the basis of economic return However, that is certainly one consideration and an important one The purpose of the example is to illustrate that there are quantitative analytical approaches to making these kinds of decisions Although quantitative analytical techniques do not furnish all the necessary information for decision making, they are of substantial help

Simulation is a technique that through modeling procedures attempts to develop an analogue of a set of inter-related activities Simulation studies are usually conducted on computers They permit the administrator to run an operation as a game before the actual activity is initiated Many types of simulation studies have been conducted The major effort has taken place in the military and business The military has simulated war games dating back several centuries to Japanese and Prussian war experiences The present military establishment conducts simulations of war games but also builds simulation trainers for such purposes as training jet pilots Business has conducted management games that allow competing firms to study consequences of different strategies of price fluctuation, advertising, and additional compensation for personnel and plant locations

The new technology for management is not merely a theoretical exercise nor is it restricted to applications in the military and industry The size and complexity of present day educational organizations have created a need for rapid and efficient methods of analysis planning and communication control in educational administrative functions No longer is it possible for the superintendent of a large school system to observe personally the many

on-going activities within an educational system Contrast the superintendent, for example, who is responsible for one, two, or three schools with twenty-five to a hundred teachers with a superintendent of one of our large municipal systems such as Chicago, St Louis, or Atlanta

The administrator in the large school system obviously cannot be personally familiar with all the personnel nor all the activities The organization must be decentralized The type of management system required maximizes individual creativity yet assures the activities are germane to the mission of the organization This assumes that the staff within the large organization is trained in certain organizational decision-making ways rather than only in human-relations activities That is, the organization must be assured that the functions relevant to the mission of the organization are conducted in such fashion that the mission will be achieved Such a management system implies a high degree of technical competence on the part of the decentralized staff

Technical competence has more meaning in an educational organization than in a business or industrial organization Suojanen elaborated upon this point

> Within the knowledge-oriented organization, administrative functions, which are not peculiar to the technical competence of the discipline, occupy a position of lesser prestige and status In the laboratory, for example, the research administrator is frequently viewed as a necessary impediment The research director possesses the technical skill to make scientific decisions, the research administrator does not, and yet he usually is involved in these issues The research administrator can take little or no credit in the accomplishment of the organization, but when failures occur he frequently gets more than his fair share of the blame Although he may occupy a high position with the formal hierarchy, his informal status among the technical specialists with whom he deals will tend to be low He can never reach the top of the knowledge-oriented hierarchy because he does not possess the necessary scientific or professional credentials His reference groups are outside the organization—among accountants or purchasing agents or "professional" managers—rather than within the knowledge-oriented discipline [1]

The quote from Suojanen illustrates a changing point of view within the administrative field The administrator with the ability to get along with people as his primary or sole resource can no longer function effectively In order

[1] Waino W Suojanen *Dynamics of Management* New York Holt, Rinehart and Winston, 1966, p 174

that the new concepts of management be implemented, new training programs are required These training programs include such courses as quantitative methods in educational administration, computer science, statistics, mathematics, quantitative business management, econometrics, and urban planning *The training programs in all administrative areas become more* technically oriented as size and complexity of systems increase

This introduction has been designed to furnish a brief exposure to the nature

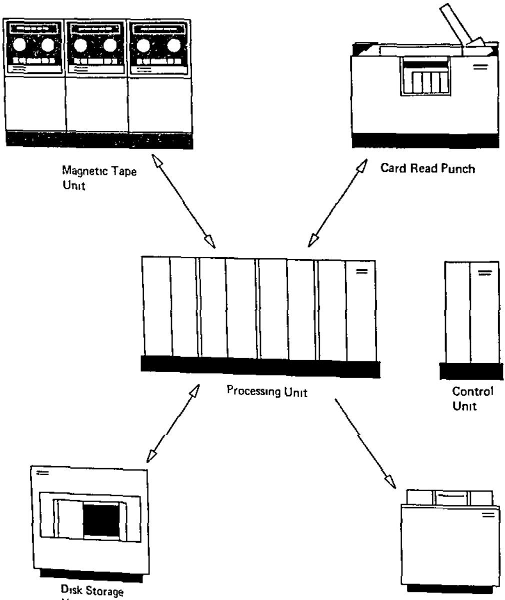


Figure 1 1 *Automated information system*

of the problem That problem has as its focal point the increased size and complexity of educational organizations As a result of the increased size and complexity, new techniques had to be developed to help the administrator with his administrative decisions

This discussion has been presented to introduce the reader to the types of problems that have been studied through systems technology Much of this book is devoted to the technology required to solve such administrative problems For this reason the illustrations in the preceding pages have been brief

Many of the problems subjected to systems analysis are associated with size and complexity Attempts at solution have concentrated on communication and control

Much has been written about communication and control Developments in computer technology, standardization of industrial process control, and the creation of a new set of mathematics and the work of Norbert Wiener in cybernetics furnish the technology far more effective and efficient control of operational processes Cybernetics, computers, and numerical analysis have developed because of increased operational complexity

A central question associated with communications and control is concerned with the methods for handling the large volume of information that originates and passes through various segments of a large organization The answer seems to be in automated information systems as shown in Figure 1 1 There are three essential aspects to be considered in the equipment configuration One deals with the preparation of input, the second deals with the actual processing, and the third deals with output

The flow chart in Figure 1 2 illustrates the through-put process from preparation of the source document to the processing center to the final destination document In addition to very rapid storage and retrieval information, the configuration has the highly desirable characteristic of analytically appraising and furnishing information about the interrelationships associated with many activities within the organization The computer configuration, then, is a massive switching device that handles the flow of information throughout the system with rapidity and accuracy Used properly, it furnishes the administrator with the capability for continuous monitoring of various aspects of the organization It is not necessarily a centralized information control center but rather a unified information control

Four case studies are given below in some detail in order that the general principles alluded to above might be more clearly illustrated

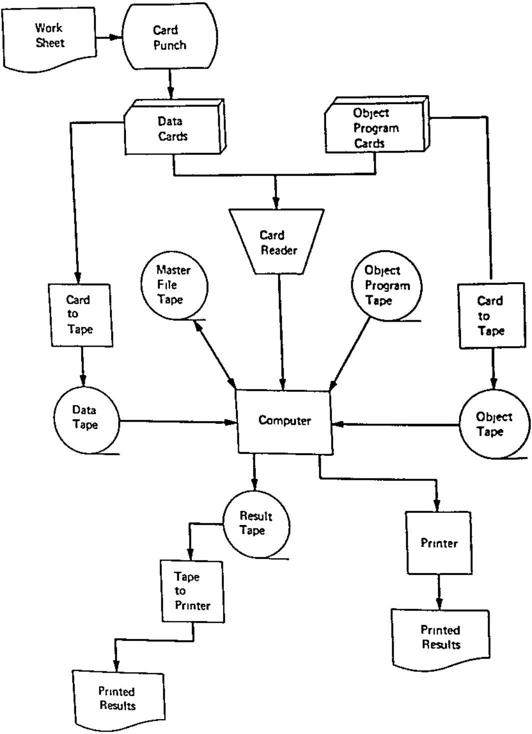


Figure 1.2. *Flow chart.*

Case I. Educational Transportation System

One of the earliest applications of the quantitative-scientific method to administrative decision-making deals with a transportation problem The transportation problem assumes that there is a required movement of materials from a set of origins to a set of destinations It is further assumed that the cost associated with the movement of materials from certain destinations differ The objective is to determine the optimal mix which sends materials from origins to destinations

The objective of the educational problem is to move students from given pickup points to given schools Figure 1.3 gives the map of the county under

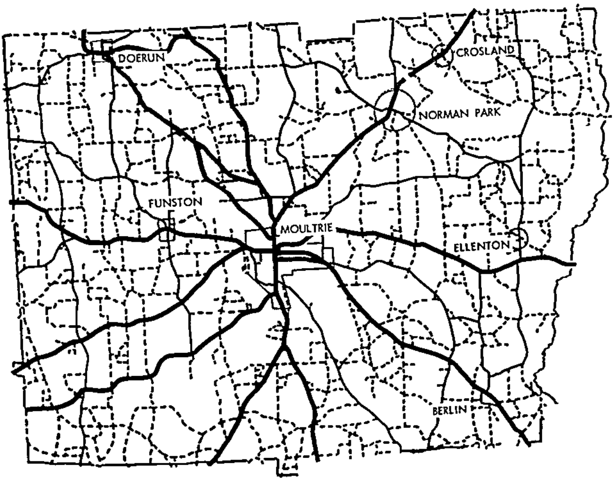


Figure 1.3. *Colquitt County.*

consideration It will be noted that the highway network is such that the distance between pickup points and schools can be designed in an almost optimal or ideal fashion Students may be picked up from any point in the county and deposited at any school If the most direct route is used, the amount of time spent in route will be negligible Theoretically, any student

within the county boundaries can attend any school that offers the appropriate grade for which the student is qualified

Figure 1 4 gives the matrix associated with the pickup points and school sites This matrix represents all possible combinations of pickup points and destinations The rows represent pickup points and the columns, schools It is apparent that a student at the pickup point in row 1 could be deposited at any of the schools in any given column that intersects with row 1 Figure 1 5 shows the cost matrix associated with transporting a single pupil between a pickup point and a school destination There is a cost entry within each cell It is intuitively clear that with time and patience, one could continue to

School Sites

Pickup Points

	S_1	S_2		S_j		S_n	Totals
P_1		P_1S_2					a_1
P_2							a_2
P_i				P_iS_j			a_i
P_m						P_mS_n	a_m
Totals	b_1	b_2		b_j		b_n	T

$$a_1 = \sum_{j=1}^{n} P_1 S_j$$

$$a_i = \sum_{j=1}^{n} P_i S_j$$

$$b_1 = \sum_{i=1}^{m} P_i S_1$$

$$b_j = \sum_{i=1}^{m} P_i S_j$$

$$T = \sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j = \sum_{j=1}^{n} \sum_{i=1}^{m} P_i S_j$$

Figure 1 4 *Pickup points—school sites matrix*

$$
\begin{bmatrix}
c_{11} & c_{12} & c_{13} & & c_{1n} \\
c_{21} & c_{22} & c_{23} & & c_{2n} \\
c_{31} & c_{32} & c_{33} & & c_{3n} \\
 & & & & \\
 & & \cdot & & \\
c_{m1} & c_{m2} & c_{m3} & & c_{mn}
\end{bmatrix}
$$

School Sites

Pickup Points	S_1	S_2	S_3				S_n
P_1	c_{11}	c_{12}	c_{13}				c_{1n}
P_2	c_{21}	c_{22}	c_{23}				c_{2n}
P_3	c_{31}	c_{32}	c_{33}				c_{3n}
P_m	c_{m1}	c_{m2}	c_{m3}				c_{mn}

Figure 1.5. *Cost matrix*

transfer students from given destinations until the total cost for operation of the transportation system would be at a minimum [That is, one could continue to transfer students, constantly looking for a cheaper route until the least expensive set of routes would be discovered] The linear programming algorithm that is the mathematical model being applied to this particular case proceeds through an iterative procedure All possible combinations of routes are checked until the least expensive overall transportation system is designed

There are several interesting things about this problem It represents a very ancient problem associated with operating educational systems transportation of pupils from their homes to school and return This problem has been solved by manual means and guesswork many times The contribution

of a scientific-quantitative approach rests in furnishing a *best* solution to the problem One not only has a *best* solution to the problem, but furthermore, knows that it is the *best* solution to the problem This kind of contribution occurs frequently in administrative decision making

Case II. Statewide Educational FM Network

This particular case furnishes information regarding management controls and administrative decision making It also denotes the similarity between organizational and engineering systems This feasibility study is designed to explore alternative systems which will furnish the state of Florida with a comprehensive statewide educational FM radio network Figure 1 6 illustrates some of the details associated with the overall management of this kind of problem All phases of the study need to be very carefully scheduled so that the study will be completed at the end of a twelve-month period

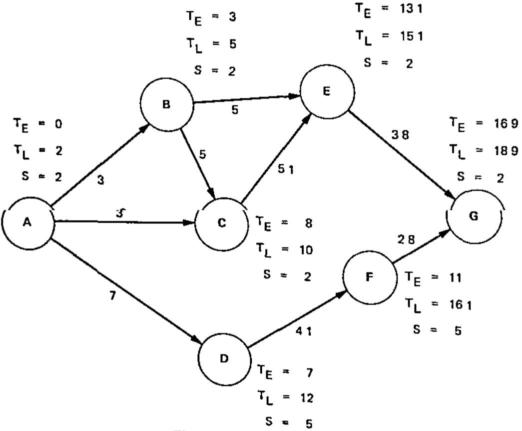


Figure 1.6. *PERT network*

Case III Fiscal Simulation

Many types of administrative problems do not lend themselves well to a small scale pilot study When the administrator is confronted with this type of problem, one of the new solutions available to him is through the technology of simulation In this particular project a statewide teacher salary increase is being contemplated Since the state legislators are concerned about spending money, there is a need to know the total cost for various alternative salary increases As a first step in this project, a salary category breakdown is made

In this particular state there are eighteen salary categories nine specific levels for salaries with a different salary scale at each level for teachers who had certain scores on the National Teacher's Examination There is also some concern on the part of the legislature to avoid an across-the board salary increase They wish to design a salary scheme that would in some way reward teachers for certain kinds of tasks of functions performed This is an attempt to increase the salary of certain teachers without promoting them to administrative posts As a result, a merit multiplier is included in the computer program along with the complete breakdown of all eighteen salary categories A computer program is written for the simulation to be run After the simulation program has been completed, the legislature is in a position to insert various salary increments into the model in addition to different merit multipliers Then, they run the model to give a total cost to the county for such salary increases

This simulation model allows the decision maker, in this case the legislature, to try various combinations of salary increments by any category, to reward different types of behavior and to get a readout on the total cost breakdown for the state and the local system All of this can be done before making a formal decision about the amount of salary increase to be recommended

Case IV. Linear Programming Model Applied to School Lunch Menu Planning

The problem of designing a menu involves such variables as taste preferences, nutrient requirements, food type costs, preparation, item balance, and seasonings Such a variety of variables exceeds any menu planner's ability to balance the variables to produce the "best" menu Because there are literally millions of possible combinations of menu items, the likelihood of discovering a "best" mix is small Use of a computer and the availability of mathematical models offers a solution

A menu is not a chance arrangement of food items. It is a carefully contrived arrangement of appetizer, entree, and dessert. The specific structure of the menu is a matter of tastes, variety, cost, nutrient value, and local preferences. More specifically, the U.S. Department of Agriculture has put forth a menu planning guide for Type A school lunches shown in Figure 1.7.

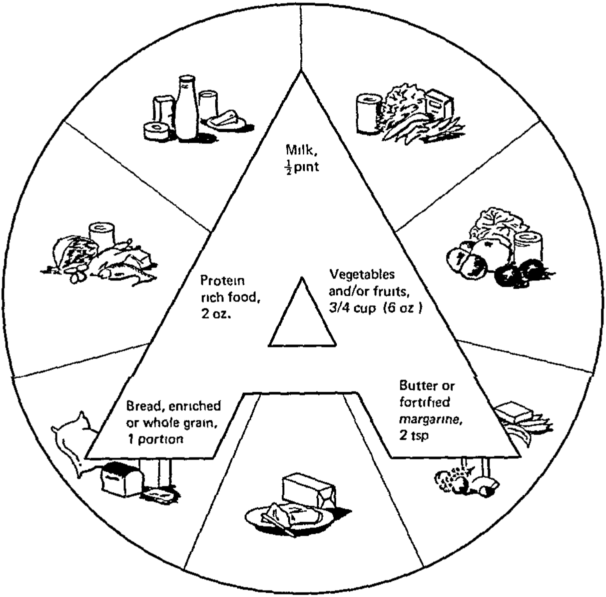


Figure 1.7. *Type A school lunches.* (From a menu planning guide, PA-719, May 1966, U.S. Department of Agriculture.)

The study is concerned only with the U.S. Department of Agriculture's type A lunch. Therefore, the model must take cognizance of the following constraints. In addition to the basic requirement there must be the element of variety. Therefore, a set of menus is designed so that duplication will be

held at a minimum One phase of the problem, then, is to find a maximum combination of items spread over a given sequence of days

Planning for an optimal menu involves a systems approach There are definite relationships among various dietary functions A truly optimal solution calls for a comprehensive systems approach Gue has suggested such an approach in hospital menu planning The model proposed in Figure 1 8 includes inventory, purchasing, and product mix

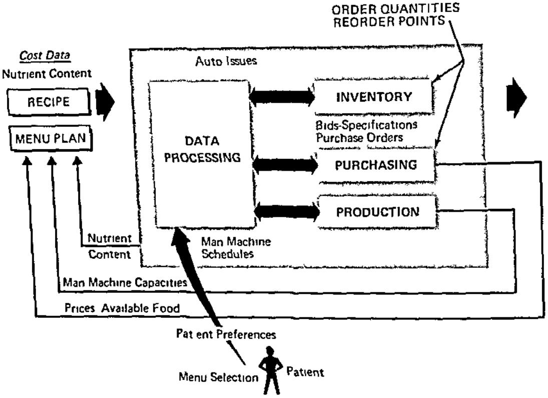


Figure 1 8 *Relationships among dietary functions* (Adapted from "Selective Menu Planning" by Ronald L Gue Unpublished, University of Florida, 1965 Courtesy of the author)

The basic guidelines in establishing a menu by computer involve a minimum nutrient intake (U S Department of Agriculture guidelines will be followed) and a reasonable variety among foods The assumption is made that meals will be served by preselective menu rather than à la carte

The use of computers in dietary management is increasing At least nine on going research projects have been reported at a recent conference held at Ohio State University Increased interest generates because of the wider applications of computers, new developments in mathematical programming,

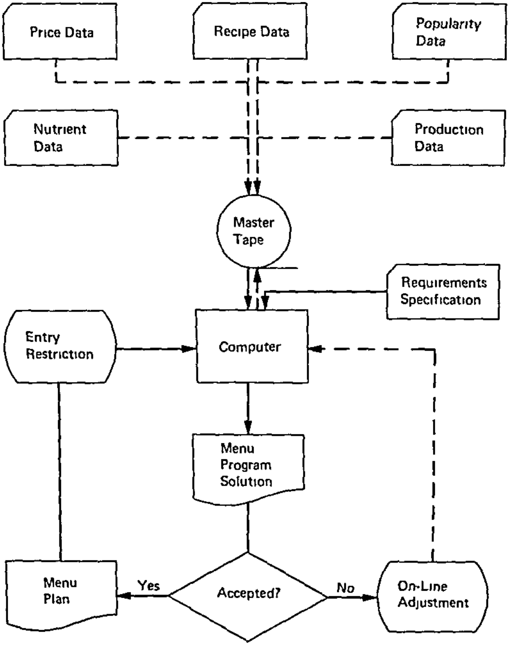


Figure 1.9. *Procedure flow chart*

and a growing sensitivity to the potential savings involved in menu planning Tulane University and the University of Florida have led much of the work in menu planning in hospitals The University of Southern New Mexico has experimented with applications to educational food services

An optimal menu mix that will meet the necessary nutrition requirements at the least cost must take into consideration student preference of taste

The procedures involve formulation of the problem, determination of the necessary constraints, and the use of the linear programming method to optimize results

M menu items are set up from *N* separate menu items available Bread, butter, and milk are offered regardless of the rest of the menu Since the age group through twelve is used, the portions are kept constant Sampling for food preferences is being done Two types of information are required The first includes recipes, prices, nutrients The second includes preferences and production feasibility

Standard recipes on hand (or made-up) are coded for use with the computer The price and nutritive value for each item is to be determined The data are transferred to punch cards Prices and nutrient contents are punched on separate cards

A card is punched for each ingredient in every recipe indicating the exact quantity of the 100-gram edible portions that are included in a single serving Also punched on cards are the preference statistics and man-hours and equipment necessary to prepare and serve each item All of these data are transferred to a master tape The computer routine combines the data from the tape and the requirements from the card to produce the best possible combination of menu items The computer output can be monitored and manual changes can be made Figure 1 9 shows the flow chart of procedures

Case V. Sundial Project

How to make a STRIKING SUNDIAL, by which not only a Man's own Family, but all his Neighbors for ten Miles round, may know what a Clock it is, when the Sun shines, without seeing the Dial

Chuse an open Place in your Yard or Garden, on which the Sun may shine all Day without any Impediment from Trees or Buildings On the Ground mark out your Hour lines, as for a horizontal Dial, according to Art, taking Room enough for the Guns On the Line and so of the rest The Guns must all be charged with Powder, but Ball is unnecessary Your Gnomon or Style must have twelve burning Glasses annex t to it, and be so placed that the Sun shining through the Glasses, one after the other, shall cause the Focus or burning Spot to fall on the Hour Line of One, for Example, at One a Clock, and there kindle a Train of Gunpowder that shall fire one Gun At Two a Clock, a Focus shall fall on the Hour Line of Two, and kindle another Train that shall discharge two Guns successively and so of the rest

Note, There must be 78 Guns in all Thirty-two Pounders will be best for this Use, but 18 Pounders may do, and will cost less, as well as use less Powder, for nine Pounds of Powder will do for one Charge of each eighteen Pounder, whereas the Thirty-two Pounders would require for each Gun 16 Pounds

Note also, That the chief Expense will be the Powder, for the Cannon once bought, will, with Care, last 100 Years

Note moreover, that there will be a great Saving of Powder in Cloudy Days

Kind Reader, Methinks I hear thee say, That is indeed a good Thing to know how the Time passes, but this Kind of Dial, notwithstanding the mentioned Savings, would be very Expensive, and the Cost greater than the Advantage, Thou art wise, my Friend, to be so considerate beforehand, some Fools would not have found out so much, till they had make the Dial and try'd it

Let all such learn that many a private and many a publick Project, are like this Striking Dial, great Cost for little Profit [2]

[2] Benjamin Franklin, as quoted in *Decision Making for Defense* by Charles J Hitch Berkeley and Los Angeles University of California Press, 1965, p 74

CHAPTER 2

Introduction to Systems

Basic Concepts

The term *systems* carries the connotation of analysis and development One assumption is that no comprehensive system development can take place without prior systems analysis *Systems* then is an inclusive term that denotes all activities involved from the original analysis of the problem through the final implementation of recommendations In general systems analysis involves utilization of scientific mathematical techniques applied to organizational operations as a part of management's decision-making activities

To say that management uses scientific and mathematical techniques as a part of decision-making procedures does not necessarily imply that decisions resulting therefrom are always correct The implication is that a more systematic approach to management problems has been used Data have been systematically gathered and utilized in the process of making management decisions Indeed, a cursory review of the literature quickly indicates that activities associated with the umbrella term *systems analysis* actually emerged from scientific management concepts

The availability of data processing hardware contributes greatly to expanding management technology enabling managers to utilize more scientific and quantitative methods for analyzing management problems Many present day systems concepts have been derived directly from the field of

engineering Although the systems engineer is concerned primarily with hardware aspects of a system, the logic of the systems engineer, the systems analyst and in many cases the operations researcher is the same In every case the procedure for making management decisions is based upon systematic collection of data, careful analysis of data, and decisions made following the analysis of data This is in contrast to the type of decision based upon an experienced man's best judgment without recourse to data

Various terms such as systems analysis, operations research, and cost benefit analysis are frequently used interchangeably There are, of course, subtleties of differences in the various activities involved The term *systems* defies rigorous definition This chapter will attempt some clarification of the term by describing the kinds of activities involved in systems studies and by presenting an overview of the basic concepts The chapter will consist of a presentation of three broad categories (1) terminology, (2) procedures, (3) criteria

Total Systems

Persons concerned with systems are technical generalists by nature They are concerned with the total operational problem and have the technical capability for analyzing the total problem The attitude of most systems analysts has been that one understands the entire operating system by carefully examining the component parts which make up the total system Emphasis throughout the investigation is upon the interrelatedness of the many parts and how these parts contribute to the total operating system Eckman and Mesarovic have pointed out the historical development of the total systems approach

was developed by Heney Paynter His interest was in the engineering systems defined, perhaps, in the broadest possible sense. The concept of energy and its transfer naturally dominates the development He was interested not only in a unified way of describing the engineering systems but also in their analysis and synthesis He was able to show the great potential value of general systems approach when applied to engineering systems [1]

Bertalanffy is one of the first who called attention to the general systems concept Although his work is in biology, the logical consequences of examining a biological system are directly applicable to the field of management. Even a superficial examination of a biological system dramatically illustrates the interdependence of the various parts and how they function in relation to one another and in relation to the total biological system Norbert Wiener's work on control and communication exemplifies importance of the total systems concept The availability and utilization of information is a necessary requisite for the total system concept

The engineer's concept of a total operating system perhaps illustrates best of all the total systems concept To build a functional engineering system without regard to the total operating system would be a disaster It reflects the difference between a technician and an engineer That is, a technician is interested in the operation of a part, but the engineer is interested in the operation of a system In an educational environment the administrator must also be interested in the total systems concept He is interested in various component aspects of the system such as staff, students, community resources, and facilities However, his chief concern is that of effective integration of all component parts into a total efficient operating system

Complexity

As modern technology has advanced and brought increased complex operations, traditional management techniques that give direction to those operations have become inadequate Because of the complex system resulting from modern technology and the inadequacy of management control, the area of systems development has come into being

[1] Donald P Eckman and Mihajlo D Mesarovic, "On Some Basic Concepts of the General Systems Theory," *Third International Congress on Cybernetics*, Namur Association Internationale de Cybernetique, 1965, pp 106–107

In most school systems the time has past when the superintendent could monitor all of the functions of the system by personal observation The superintendent, therefore, needs access to modern techniques to monitor the system on a day-to-day basis in order to make effective decisions about the school system The superintendent is faced with the same kinds of problems that have confronted military and government management This also, is pointed out by Deutch

> In the simpler systems—where you can vary one factor at a time—the methods of conventional and automated analysis is sufficient But, in dynamic and interconnected complex systems, the alteration of one factor immediately acts as cause to evoke alterations in one or a great many others Until recently, government tended to evade the study of such systems, focusing its attention on those that were simple and, especially, reducible In the study of some systems, however, the complexity could not be wholly evaded The human economic system is outstanding both in its practical importance and in its intractability by the older methods So today we see societies declining, and economic systems faltering, the scientist being able to do little more than to appreciate the full complexity of the subject he is studying But science today is also taking the first steps toward studying "complexity" as a subject in its own right Cybernetics is one of the most outstanding methods for dealing with complexity It respects the vaguely intuitive ideas that we pick up from handling such simple statistics as income or balance of payments data, or capital input-output data, and sets to work to a rigorous discipline of sound practical planning [2]

Management can no longer afford a lengthy time-lag in making decisions This is true in school systems as well as in government The complexity of the system can no longer be evaded It is encumbent upon the present day manager, therefore, to find new ways of handling the decision-making process associated with a complex operation The manager is concerned with day-by-day operating decisions Plans must be made in a highly flexible atmosphere, and decisions must be made based upon the best possible data available Operations in a complex organization reflect a highly dynamic system One must rely upon a highly dynamic technology to assist in a day-by-day decision-making process It is in this context that the systems approach is

[2] Michael J Deutch, "The Applications of Cybernetics to the Professional and Scientific Operations of the U S Government," *Third International Congress on Cybernetics*, Namur Association Internationale de Cybernetique, 1965, p 640

most effective Managers have now become aware of the necessity for this approach

The scientific and engineering interest in systems approach has developed primarily because of the need for a more rigorous approach to very large, complex and interrelated phenomena in the physical (scientific) world, in the man-made (engineering) world and in the man organized (sociological) world Although this need has been evident for a long time, it is only recently that man has at hand the computational tools, such as large and fast electronic computers, to attempt to deal with the analysis of large and complex problems

One of the characteristics of the systems approach is extensive use of the computers for obtaining the information about the system's behaviour or via experimental mathematics for synthesis of the complex systems This fact requires special emphasis on the development of a conceptual basis which will offer the context for the analysis or synthesis of a system Just when there is a lack of complete analytical rigor in the study of the system because of its large complexity, the correct conceptual framework becomes essential [3]

The availability of high speed data-handling equipment adds two dimensions to the system process One greatly reduces the time lag for making decisions, and the other allows a management decision maker to base decisions upon more comprehensive data Since management decisions are essentially stochastic in nature, the greater amount of data upon which decisions are based adds to the rigor of the study and a reduction in the error It is interesting to note that complexity has taken on dimensions such that fields of inquiry have come into existence for the sole purpose of studying the problem of complexity

The study of pure cybernetics as it concerns the theory of systems is approaching a stage where the problems which remain interesting are too complex to handle by conventional methods At such a time original research must be concerned with the search for new methods of solution The theory of logical networks as used in computers is already well understood, but the computers themselves are verging on the limit of constructibility and improvements in this field constantly await the success of the technologists in producing new and smaller components On the

[3] Eckman, *op cit*, p 105

conceptual side progress is limited by an inability to express complex networks in terms of words or other familiar symbols [4]

Approaches to the problem of complexity have required new developments in the field of mathematics To a much greater extent the present day managers must have some quantitative orientation This is not to say that all managers must be mathematicians However, those responsible for the operation of highly complex systems today simply cannot function effectively without an appreciation of present-day technology Present-day technology is essentially based upon scientific and mathematical disciplines

Definitions

A recognition of the fact that such new disciplines as systems procedures have applications to the field of education has been recognized by noneducators such as Chorafas

> In the course of the evolution of human knowledge we have experienced the growth of new and promising disciplines One of them is systems analysis Its foundations have been derived from studies of dynamic systems and their functioning components A system is a group of interdependent elements acting together to accomplish a predetermined purpose *Systems analysis* is an attempt to define the most feasible, suitable, and acceptable means for accomplishing a given purpose
>
> The systems analyst, like the natural scientist, must limit his range of endeavor The natural scientist contents himself with describing the most simple events that can be brought within the domain of his experience All events of a more complex order are beyond the power of the human intellect to reconstruct with the subtle accuracy and logical perfection which the theoretical physicist demands For his part, the systems engineer must content himself with the study and analysis of complex technological systems, with the understanding of the nature and the workings of systems components, and with their synthesis into a working ensemble [5]

[4] Bernard L M Chapman, "A Shorthand Notation for Large Active Networks," *Third International Congress on Cybernetics*, Namur Association Internationale de Cybernetique, 1965, p 280

[5] Dimitris N Chorafas, *Systems and Simulation*, New York Academic Press, 1965, pp 2–3

The key contribution of Chorafas' definition involves the idea that there are component parts which synthesize into a total functional system In this sense the more technical definition of a system corresponds roughly with the dictionary definition of a system This same essential concept of "an integrated assembly of interacting elements" has been expressed by Flagle

> To begin with a definition, a system is *an integrated assembly of interacting elements, designed to carry out cooperatively a predetermined function* The living organism, the animal, or above all, the human body with its central nervous system, is an example *par excellence* of a system Indeed, the human body is the primary source of our fundamental ideas about systems St Paul used the body to illustrate a social system, the Church, "But now are they many members, yet but one body" Following the human habit of making anthropomorphic models, we have used ideas gained intuitively from personal experience to understand new phenomena or to devise new creations [6]

A concise statement by Morton encompasses many essential features of systems procedures

> The Systems Engineering method recognizes each system as an integrated whole even though composed of diverse, specialized structures and subfunctions It further recognizes that any system has a number of objectives and that the balance between them may differ widely from system to system The methods seek to optimize the overall system functions according to the weighted objectives and to achieve maximum compatibility of its parts [7]

Implied in Morton's reference are several systems concepts including optimization, systematic analysis, quantification, and maximization Such concepts suggest that systems work is basically a procedure for management decision making based upon data and analysis rather than intuition One could read the various textbooks and other references listed at the end of this chapter and find variations of this same theme

[6] Charles D Flagle, William H Huggins, Robert H Roy *Operations Research and Systems Engineering* Baltimore The Johns Hopkins Press, 1960, pp 58–59

[7] J A Morton, "Integration of Systems Engineering with Component Development," *Electrical Manufacturing*, LXIV (August, 1959), pp 85–92

Cybernetics

The term cybernetics has come to denote that discipline associated with the investigation of communication and control Its relevance to systems study is quite specific Communication and control suggest a concern for component elements of a system and for how they might function together to produce the most effective integrated system Although the term cybernetics as used by Norbert Wiener has been associated primarily with the physical systems of engineering and physics, its original usage by Ampere is a reference to government

> The celebrated physicist and mathematician A M Ampere coined the word *cybernetique* to mean the science of civil government (Part II of "Essai sur la philosophie des sciences," 1845, Paris) Ampere's grandiose scheme of political sciences has not, and perhaps never will, come to fruition In the meantime, conflict between governments with the use of force greatly accelerated the development of another branch of science, the science of control and guidance of mechanical and electrical systems It is thus perhaps ironic that Ampere's works should be borrowed by N Wiener to name this new science, so important to modern warfare The "cybernetics" of Wiener ("Cybernetics, or Control and Communication in the Animal and the Machine," John Wiley and Sons, Inc , New York, 1948) is the science of organization of mechanical and electrical components for stability and purposeful actions A distinguishing feature of this new science is the total absence of considerations of energy, heat, and efficiency, which are so important in natural sciences In fact, the primary concern of cybernetics is on the qualitative aspects of the interrelations among the various components of the system and the synthetic behavior of the complete mechanism [8]

Ampere attempted to relate the concept of cybernetics to nonphysical areas of inquiry, and at present persons interested in cybernetics are attempting to use the technology in the nonhard sciences Although Ampere's use of the term almost one hundred years before Wiener's development of the cybernetic theory did not bring about a systematic approach to governmental problems, it illustrated the slow evolution of ideas in a scientific study The more sophisticated development of technology by Wiener's time no doubt

[8] H S Tsien *Engineering Cybernetics* New York McGraw Hill Book Company, 1954, Preface, vii

contributed to the acceptance and expansion of the basis idea An attempt to associate the term with the physical sciences was made in one of Wiener's earlier statements

> Until recently there was no existing word for this complex of ideas, and in order to embrace the whole field by a single term, I felt constrained to invent one Hence cybernetics which I derived from the Greek word *kubernetes* or steersman—the same Greek word from which we eventually derived our word governor [9]

The reference to the term *cybernetics* as being analogous to *governor* associates the term with an engineering system It is a control devise of a mechanical nature that feeds upon internal feedback for purposes of control The wide range of applications of cybernetics is illustrated in the report of Deutch

> Cybernetics is defined by Wiener as "the science of control and communication, in the animal and the machine" It is the art of steermanship, and it is to this aspect of government operations that this paper is addressed Coordination, analysis, storing and control of data and information are of the greatest practical interest in the newest and fastest growing activities of the U S Government, wherein the use of cybernetics promises to be of greater assistance than automation I shall confine my attention to the applications that are not simple derivations of modern memory storage or computing machines, which already are in great use throughout the Bureau of the Census, the Post Office Department, the Government Printing Office, the General Accounting Office and that of the Comptroller General of the U S , and other areas where the volume of work and the need for speed constitute ideal applications of automated mailing, addressing, calculating and statistical control machines, and of related electronic devices [10]

Here Deutch brings out the fact that the development of cybernetics is closely allied to the development of computers and other related technology The combination of technology and hardware is of maximum assistance to the manager in his monitoring and control of complex organizations Continuous monitoring and control of a military guided missile system furnishes

[9] Norbert Wiener *The Human Use of Human Beings* New York Doubleday Anchor Books, 1956, p 16

[10] Deutch, *op cit*, p 639

an excellent analogue for development of a comprehensive management system

Much of systems theory is based upon a concept of internal monitoring and consequent modification of functions This internal monitoring and consequent modification of functions is essentially what is meant by feedback The term feedback is a functional one for descriptive purposes in biological systems as well as physical systems The field of cybernetics brought the term into prominence where it was formalized as an inherent part of internal control in communication, an essential characteristic of cybernetics

One of the first detailed descriptions of a feedback system used as a control was described in Clerk Maxwell's paper "On Governors" which was published in 1868 Maxwell's governor was a built in servomechanism that controlled the speed of a running motor A more sophisticated application of feedback theory was presented much later when Minorsky in 1922 published his paper on "Directional Stability on Automatically Steered Bodies" Ten years later Nyquist published "Regeneration Theory" Only two years later in 1934, Hazen published a paper on "Servo-Mechanisms" By this time the mathematical theory of feedback control had been more or less worked out

In World War II, as weapon systems became more sophisticated, more sophisticated means for controlling weapon systems were required Impetus was given to feedback control systems as a result of the demands made by fire systems Following World War II and with the advent of computers, concepts of feedback control were more widely applied in various areas of scientific and technological applications and contributed to many new areas of applied mathematics Feedback is a broad term somewhat similar to systems Here is a reasonably comprehensive discussion of the concept, which was presented at the Third French Conference by Eckman and Mesarovic

> Appearance of the cybernetics as an interdisciplinary and abstract science of control and communication was preceded by the following two historical occurrences (a) increased use of the control devices in various engineering systems indicated that one and the same pattern is used in solving the control problems, i e via feedback This necessitates a closer look at the structural pattern from the mathematical, i e, abstract viewpoint, (b) knowledge of some of the biological systems was developed to the point at which it was possible to show that the feedback is used as a method for solving the control problems in such systems [11]

[11] Eckman, *op cit*, p 105

Numerous applications have been made of feedback theory in the area of control These applications have not been restricted to engineering applications but have extended to various other areas including areas of social activity which include school systems

> A refrigerator temperature control has a thermostat to measure the actual temperature, electrical contacts to measure the error between the actual and the desired temperature, and a compressor motor for power amplification In this case, the motor is either on or off, depending upon the sign of the error
>
> The scheduling and regulation of a production line or manufacturing process is also a feedback system The controlled variable is production rate or inventory level, and the desired value is obtained from a computer attempting to minimize costs or maximize profits, including the characteristics of the market The error is used to compute the ordering rate for raw materials and labor The power supply is the money available
>
> Consider our school system When the error between what the parents want their children to learn in school and what the children actually receive becomes too great, the school board feels this force of public opinion and changes the school policies In such a manner, the schools are regulated by the mores of the community All regulatory bodies throughout our entire society are feedback control systems corporation boards, Interstate Commerce Commission, Federal Communications Commission, and the government itself Any device or economic, political or sociological system to which can be ascribed the terms regulatory, or governing, controlling is usually a feedback system [12]

To fully understand the applications of the term *feedback*, one needs to be pragmatic It does not have a specific scientific meaning that applies only to physical or engineering systems

Open and Closed Systems

The concept of closed and open systems involves the interaction of a given system with its immediately adjacent environment A closed system is one in which a boundary is placed around the system The implication is made that interaction takes place among those segments of systems within the boundary

[12] O J M Smith *Fedback Control Systems* New York McGraw-Hill Book Company, 1958, p 3

and segments of perhaps another system outside the boundary. This closed system has been described by Chorafas

> In mathematics, when talking of systems we mostly have in mind a set of laws In the physical sciences we use the word *system* to mean a portion of the universe around which we draw an imaginary boundary, for the purpose of study of what is enclosed inside this boundary In engineering the word "system" is mostly interpreted as meaning an organized working total, an assemblage of objects united by some form of regular interaction or interpendence Systems may themselves be subsystems of other larger ensembles Hence the idea of drawing an imaginary boundary holds true with every usage of the systems concept [13]

Chorafas points out that if one considers the system at any particular time as being defined by those interacting component parts and by a given system being there for a subsystem of another system, one merely expands the imaginary boundary to keep the system closed

Bertalanffy was one of the first to call attention to the open system

> From the standpoint of physics the characteristic state in which we find the living organism can be defined by stating that it is not a closed system with respect to its surroundings but an open system which continually gives up matter to the outer world and takes in matter from it, but which maintains itself in this continuous exchange in a steady state or approaches such steady state in its variations in time
>
> So far physical chemistry has been concerned almost exclusively with processes in closed systems Such processes lead to chemical equilibria Chemical equilibria are also basic for certain processes within the organism For example the transport of oxygen from the lungs to tissues is based on the chemical equilibrium between oxygen hemoglobin and oxyhemoglobin In the lungs where there is high oxygen tension, blood is charged with oxygen which combines with the hemoglobin to form oxyhemoglobin In the tissues at a lower oxygen tension, the oxyhemoglobin dissociates and oxygen is released Here chemical equilibrium is reached because the processes concerned are the high reaction rate The organism as a whole is however never in true equilibrium and the relatively slow processes of metabolism lead only to a steady state maintained at a constant distance from true equilibrium by a continuous inflow and outflow building up and breaking down of the component materials [14]

[13] Chorafas, op cit, p 4

[14] Ludwig von Bertalanffy *Problems of Life* New York John Wiley & Sons, 1950, p 125

Bertalanffy goes on to discuss the consequences of the thermodynamics of open systems In the new vistas in physics and biology that have been opened because of the concept of open systems, he discusses in detail the steady state that a system approaches as it interacts with its adjacent environment This considers the system as being in dynamic equilibrium and probably fits more adequately most biological and sociological data However, again the emphasis was upon physics as Bertalanffy expressed the concept Even though he was discussing a biological system, the idea of interaction described by closed loop has also been applied to economic theory

> Since Keynes in the thirties displayed the essential structure of the economic mechanism of an industrial society as a closed-loop, engineers have been intrigued by the analogy with an electrical or mechanical automatic-control system [15]

The Dow-Jones theory of the ebb and flow of the stock market probably follows the same basic principles that illustrate the economic system reacting to pressure from the environment Comparable to the ebb and flow of the stock market is the population growth as organisms react and interact with their environment

> A slightly analogous problem arises in the animal world in the relationship between predator and prey An increase in the numbers of a creature which is prey to another animal represents an increase in food supply to the predator and may therefore stimulate an increase in the number of the latter But an increased number of predators may rapidly reduce the number of prey, which in turn will impose a restriction on the number of predators and so it goes on as a relaxtion oscillation As feed-back theory tells us, a powerful source of instability is delay within the closed loop, and in the animal problem the delay is that involved in the production of a new generation There is also a special risk in the biological case —the risk of extinction For if the number of one species ever falls to zero, it can never rise again, whatever happens to the number of the other species even if the human race disappeared, the dodo would remain extinct [16]

Indeed, this type of interaction has been subjected to systematic mathematical analysis Sets of differential equations predict quite effectively the

[15] D A Bell *Intelligent Machines An Introduction to Cybernetics* London Sir Isaac Pitman & Sons, 1962, p 80

[16] *Ibid*, p 83

›b and flow of population growth and development A further amplification f the concept of an open system is given by Wiener

> We, as human beings, are not isolated systems We take in food, which generates energy, from the outside, and are, as a result, parts of that larger world which contains those sources of our vitality But even more important is the fact that we take in information through our sense organs, and we act on information received
>
> Now the physicist is already familiar with the significance of this statement as far as it concerns our relations with the environment A brilliant expression of the role of information in this respect is provided by Clerk Maxwell, in the form of the so-called "Maxwell demon," which we may describe as follows
>
> Suppose that we have a container of gas, whose temperature is everywhere the same Some molecules of this gas will be moving faster than others Now let us suppose that there is a little door in the container that lets the gas into a tube which runs to a heat engine, and that the exhaust of this heat engine is connected by another tube back to the gas chamber, through another door At each door there is a little being with the power of watching the on-coming molecules and of opening or closing the doors in accordance with their velocity
>
> The demon at the first door opens it only for high-speed molecules and closes it in the face of low-speed molecules coming from the container The role of the demon at the second door is exactly the opposite he opens the door only for low-speed molecules coming from the container and closes it in the face of high-speed molecules The result is that the temperature goes up at one end and down at the other thus creating a perpetual motion of "the second kind" that is, a perpetual motion which does not violate the first law of thermodynamics, which tells us that the amount of energy within a given system is constant, but does violate the second law of thermodynamics, which tells us that energy spontaneously runs down hill in temperature In other words, the Maxwell demon seems to overcome the tendency of entropy to increase [17]

Entropy and Randomness

Much systems work has grown from work in engineering and physics Two closely related concepts used quite frequently in systems thinking are entropy and randomness Entropy implies that a system tends to degenerate into disorder Randomness assumes that any event has an equal opportunity

[17] Wiener, *op cit*, pp 28–29

of occurring Order grows from the random occurrence of events If a system grows without continuous monitoring, there is a tendency for entropy or disorder to continue The concept is significant in systems work because the assumption is that one not only designs an effectively operating system but must continue to monitor the system

> In the 19th century, scientific progress was always associated with order, system and coherent sequence of cause and effect the scientist classified his observations with mathematical precision, marshalled his facts with the orderliness of soldiers on ceremonial parade, and constructed a theory which ran like clockwork Even after Darwin's work on the origin of species, the popular view of evolution was that the universe could now be regarded as a vast mechanism which automatically, inevitably and systematically worked through the selection of favourable species to the attainment of desirable biological ends Meanwhile, the last day of judgement was banished along with the creation Just as direct divine creation was replaced by the gradual process of evolution, so the dramatic "Last trumpet" was replaced by the mean but remorseless running down of the universe—entropy always increases, *i e*, disorder increases and that is a broad thing
>
> That this view is now clearly insufficient was brought home to the author some time ago when a zoologist opened a discussion on the comparison of the directive methods used in nature with the "cybernetics" of modern engineering Consider the problem of a woodlouse which can only live in a humid atmosphere and therefore desires to find a damp spot A single sensing organ could not find the direction in which greater dampness lay in the same way that an eye can find the direction of a source of illumination, a physicist would perhaps think of solving such a problem by setting up two or more moisture sensitive devices a small distance apart in order to find the gradient of the humidity, but the woodlouse is too small to span the distance necessary for the humidity to change significantly Nature, however, provides a simpler method by inducing the woodlouse to start random or disordered process as the most economic solution to a problem Apart from the fact that the random search process requires no additions to the organs which are already needed for other purposes, it is the only economic solution to this problem since a gradient-measuring device is not practical [18]

The fact that events occurring at random do not necessarily imply that randomness is bad is clear from Bell's discussion The development of

[18] Bell, *op cit*, pp 87–88

mathematical statistics has freed scientific thinking to a considerable extent and has demonstrated the utility of applying the concept of randomness to both physics and less systematic disciplines Wiener has also pointed out the relationship between entropy and systems

> We are immersed in a life in which the world as a whole obeys the second law of thermodynamics confusion increases and order decreases Yet, as we have seen, the second law of thermodynamics, while it may be a valid statement about the whole of a closed system, is definitely not valid concerning a non-isolated part of it There are local and temporary islands of decreasing entropy in a world in which the entropy as a whole tends to increase, and the existence of these islands enables some of us to assert the existence of progress What can we say about the general direction of the battle between progress and increasing entropy in the world immediately about us?[19]

The problem in any type of systems activity is to retain the integrity of the system and to try to minimize the tendency of the system to degenerate

Control

Systems theory has been closely associated with the development of engineering and control systems The ultimate objective of most systems studies has been directed toward a more effective control of component parts of the organization and a consequent more optimal functioning of the system Therefore, the concept of control is central to any systems work The discipline of cybernetics has been concerned primarily with feedback systems that involve internal communication and control The primary contribution of cybernetic theory to systems theory rests with the three concepts of feedback, communication, and control

> The past several years have been notable in the field of control and information systems for the phenomenal growth of interest in the concept of adaptive control and self organizing systems Adaptive control may be viewed as a type of control in which automatic and continual measuring and estimating of the dynamics of the process to be controlled are used as the basis for the continuing self-adjustment and self-design of the control

[19] Wiener, *op cit*, pp 36–37

system Adaptive control systems are systems which attain a specified or optimum performance in spite of large variations in system parameters Adaptive control systems change their parameters through some automated means, but their structure remains unchanged Self organizing systems, on the other hand, change both parameters and structure through some automatic or self generated means Self organizing systems may be considered as more sophisticated adaptive control systems A brain learning complex, a computer logic design, an economic system and an industrial management system may be self organizing, because they call into play at different times a completely different logic or operating structure depending upon either internal or environmental conditions

The need for adaptive control and self organizing system occur when the parameters and structure involved in the design of the system change in time For small variations, conventional feedback configuration can sometimes reduce the sensitivity of the output to these changes to acceptable values, but large variations of the parameters and structure require a more flexible system The newer adaptive and self organizing point of view in designing a control system can, in general, allow for changes in input signal characteristics, plant characteristics, disturbance characteristics and system structure with a minimum amount of a priori knowledge The steering of an automobile by a man is a common example of adaptive control The driver continually injects small variational [test signals on the steering wheel in order to maintain the feel of the road and his car By doing so, he is continually measuring and estimating the dynamics of the process which he is controlling so that he may be prepared to effect optimum or near optimum control when input and disturbance signals arise [20]

Although control systems are given a great deal of impetus as a result of military fire systems, the idea of adaptive control has spread to work in biology and the social sciences Development of computer systems has greatly assisted in development of scientific theory dealing with control A primary contribution control theory has made toward management science is the concept of continuous monitoring Indeed, many of the functions formally requiring human intervention have now been completely automated and subjected to internal control systems that are managed by computers Rapid development of total information systems within larger school districts is indicative of direct application of control theory to management functions

[20] Julius T Tou and King Sun Fu, "Digital Control Concepts for Nervous System Synthesis and Simulation," *Third International Congress on Cybernetics*, Namur Association Internationale de Cybernetique, 1965, p 795

Quantification

The methodology of systems analysis has been based primarily upon mathematics The true contribution of systems procedures has rested with the ability of the analyst to quantify his concepts and derive solutions from that quantification Because of the quantitative orientation of systems analysts, there has been some historical confusion between systems analysis and operations research

Confusion in the literature regarding systems analysis and operations research has been over whether or not the two phrases are synonymous In general, the phrase systems analysis is more comprehensive and implies a wider look at the problem The phrase operations research denotes one of a set of specific mathematical techniques for problem analysis

The field of operations research has become almost exclusively mathematically oriented Indeed, it could be considered a subset of mathematical analysis Systems analysis on the other hand embraces qualitative as well as quantitative techniques A systems analysis attempts to look at the total operating organization in the beginning even though eventually the analysis is done upon some component subsystem The invariant factor common to both systems analysis and operations research is the scientific orientation that both bring to bear upon management problems

Systems Procedure

Introduction

There is no cookbook recipe that furnishes the systems analyst with a step by-step outline to perform systems work However, the systems analyst does not perform without general guidelines This section of the chapter is designed to furnish an overview of five major considerations for the systems analyst systems analysis, systems design, systems evaluation, systems operations, and systems monitor This procedure is illustrated in the Figure 2 1

The flow chart in Figure 2 1 indicates the continuous nature of systems work From the beginning one goes to a comprehensive analysis of the system A new system design is created as a result of the analysis An evaluation is

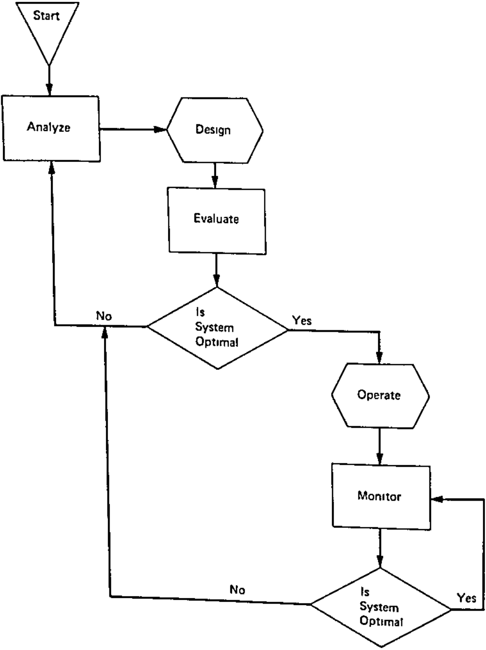


Figure 2.1. *Flow chart*

made of the new design The question is asked as a result of the evaluation Is the new system functionally optimal? If it is not, an additional analysis is made and the latest design is modified A new evaluation is made, and again the question is asked Is this new system functionally optimal? This loop is continued until the new system is optimal, and the new system then is implemented and operated Once the new system is operational, continuous moni-

toring is made The question is constantly presented Is the new system optimal? If it is not, again analysis is made, a new design is created New evaluation is made until the new system continues in optimal fashion If the new system is optimal, the analyst continues monitoring it Figure 2 1 illustrates how continuous monitoring of the new system keeps the new system in a functional state

Systems Analysis

There is a series of steps through which one must proceed in order to accomplish a systems analysis Whether or not one uses the steps enumerated below as an official checklist is irrelevant However, each of the steps must be accomplished before the systems study is complete

Step One—Establish Objectives The most difficult part of the entire systems study involves establishment of very specific objectives to be accomplished Because of the quantitative nature of systems analysis, it is necessary to be extremely specific in determining the objectives to be achieved To state objectives in general terms such as improvement of curriculum, enhancement of the educational system, or development of a better building program is totally inadequate To list the reevaluation of the fiscal system as an objective for instance, would be inappropriate A systems study would entail automating the fiscal procedures Cost benefit analysis would be used Staff utilization and flow charting would complete the fiscal system by stipulating the details of all fiscal functions involved in the total school system

Step Two—Review of Systems Operations The second step in systems analysis involves a comprehensive review of all the systems operations Since systems analysis is problem oriented, one does not always perform the analysis on the total operation It is, however, necessary to understand completely the systems operations before one can thoroughly delineate the problem to be studied It is almost a truism in education as in industry that the problem which the administrator feels to be the main problem does not always turn out to be the main problem Under any circumstances a systematic review of the total system is necessary in order that the analyst can understand the setting in which the problem to be solved rests

Step Three—Collection of Data Following review of the total system and isolation of the apparent problem area, the analyst begins to collect detailed

data within the problem area At this point, the system analyst diverges from the traditional way of administrative decision making Traditional in the sense that one reviews operations and makes intuitive judgments from the review Collection of data involves basically a statistical procedure In many situations, aspects of systems analysis are applications of classical statistical procedures This is true because of the nature of an educational system There is not too much subject to deterministic mathematics If one gets into the mathematics of probability, one deals with classical statistical techniques

Step Four—The Analysis of Data Analysis of data is discussed separately from collection of data in order to point out the distinction between a systems analysis and the traditional experimental paradigm in research The experimenter in the social sciences has generally followed the model of the physicist That is, his experiment involves a dependent and an independent variable Manipulation of the independent variable is followed by systematic measurements made upon the dependent variable In classical fashion cause and effect relationships are studied and determined This type of classical experimental paradigm, however, assumes that the investigator knows in advance specifically which variables are to be controlled and investigated In a systems analysis one begins the analysis with the objective of determining just which variables are relevant Where the classical experimenter is concerned with manipulation of variables in the dependent and independent sense, the analyst is concerned with a study dealing with interaction of many variables Causality is not necessarily the primary concern Correlation becomes the primary concern

Step Five—Isolation of the Problem As indicated earlier, the administrator does not always know precisely what the problem is It is necessary to go through the systematic review, data collection, and analysis of data in order to determine the specific problem Isolation of the problem then follows the sequence of steps that allows one to spell out in precise detail the nature of the problem Although systems analysis is a comprehensive concept and one which begins with the big picture, the techniques are essentially problem oriented and require isolation, specificity, and definition of the problem

Step Six—Specify Operations in the Problem Area Once the specific problem has been isolated, it is necessary to do a detailed comprehensive review of those operations within the problem area This review is much more detailed

than the original review of the total operations One, in effect, builds a detailed model of the problem area operations in order to understand quickly the relationship of all facets of the problem area to the total operating system

Step Seven—Block Diagram The problem area has a final step in the analytical stages of the systems analysis Yet, prior to building a new design, one builds a block diagram of all functions of the subsystem that makes up the problem area This block diagram is based upon the prior model, which is an outgrowth of the analysis of specific operations in the problem area The block diagram denotes logical structure of the subsystem operations and is similar to the block diagram and figure that sketched out a systems analysis

System Design

After the system analysis the analyst attempts to design a tentative solution to the problem Before any implementation of the new solution is made, that new solution is subjected to testing Following the test, necessary corrections are made to the tentative solution, and the modified tentative solution is again subjected to tests This loop consisting of a tentative solution testing the tentative solution, modifying the tentative solution, and retesting the tentative solution continues until the analyst converges upon an optimal solution Once the optimal solution is found, the analyst departs from that loop

System Evaluation

The formal evaluation of the new solution follows essentially the same loop that the small testing procedures followed in checking out the tentative solution The primary difference between the formal evaluation may involve (and usually will) implementation of the tentative solution in some aspect of the system As the formal evaluation proceeds, modifications are made to the operating system, reevaluations are made, new modifications are made, and once again the analyst proceeds through the same type of loop indicated earlier Not all evaluations are made in actual operational trials Many are conducted through simulation However, at this stage it is probably advisable to test out or evaluate all new system solutions in a small segment of the required operation

System Operation

Following formal evaluation and acceptance of the solution to the problem, the new design has been implemented and placed in total operation within the system There are really two aspects involved (1) concern with implementation of the new system operation and (2) maintenance of the system This distinction is made in order to call attention to the fact that one needs to be concerned about the maintenance of the system when a new system is designed

System Monitor

Once the new system is in operation an inherent part of systems procedures involves continuous monitoring of the system in order to check on the effectiveness of the system The objective of this continuous monitoring is to detect less than optimal functions of the system and in this fashion make improvements upon the new system In effect the system monitor continues the basic philosophy of a systems study It affords the administrator an opportunity to constantly analyze the system make new tentative designs for improvement of the system, evaluate improvements and old functions of the system, and operate and maintain the system

Criteria for Evaluating Systems Projects

Any systems evaluation scheme must include at least the following four general categories performance, cost, utility, and time The general criterion is that the total system should operate in an optimal fashion This means that many suboptimizations and their relations to the total functioning system must be taken into consideration Frequently, it is discovered that subsystems must function in less than optimal fashion in order that the total system may operate optimally

Performance

An evaluation of performance is done in terms of effectiveness The design of the problem solution determines how effective the new system will be in fulfilling the organization's mission It is necessary to devise standards for

measuring effectiveness These standards might be derived from norms within or outside the system One might wish to develop a standard of current operation efficiency and compare the new system with that current standard Frequently it will be necessary to utilize standards from without the system and bring the system up to the level of outside standards Throughout the systems study the assumption is made that organizational objectives have been clearly and concisely stipulated Often much groundwork is needed before it is possible to derive any clear cut statement of objectives Because of the quantitative aspect of systems analysis, it is necessary that objectives be stated in very specific terms Outcomes are stated in attainable terms

Inherent in establishing the performance criteria is the concept of validity Validity is used here in the statistical sense as in psychological testing That is, the procedure or performance is valid if it does what it is supposed to do Therefore, the problem solution is valid if the solution accomplishes what it is supposed to accomplish Much of the evaluation of performance is qualitative However, the contribution of systems analysis is primarily its capacity to bring quantitative procedures to bear upon management decision making To a much greater extent performance is subjected to quantitative evaluation in a systems study

The term reliability is used here also in a classical statistical sense, meaning that a function performs consistently in the manner in which it is performing A reasonable distinction between reliability and validity has been given by Guilford

> Common synonyms for reliability include *dependability*, *consistency and stability* Each means something different as applied to measurements Even the same term has slightly different meanings as applied to different measurement operations Common synonyms for validity include *relevance, discrimination, value*, and *predictive value* [21]

As a part of evaluation of performance, the problem of maintenance of the system is of primary importance Consideration must be given to cost, personnel, and facilities in evaluating maintenance of the system

Cost

Analysis of systems is influenced by cost function to a major extent The expected outcome of a systems analysis is concerned with the problem of

[21] J P Guilford *Psychometric Methods* New York McGraw Hill Book Company, 1954, p 342

allocation of resources Although the resources include personnel and facilities in addition to cost, in some fashion one is usually confronted with the problem of allocating fiscal resources or those functions dependent upon fiscal resources Primary motivation for performing a systems analysis is to furnish the decision maker with a reasonable basis for making the choice among alternatives The administrator must deliberately train himself in the art of selecting from alternatives and thinking in terms of alternatives Increasingly technology has made available to the administrator techniques that give him with a more solid basis for making decisions or selecting from among alternatives In order to make decisions on the basis of selection from a clear-cut set of alternatives, one must have comprehensive data about the relevant aspects of the system For example, if a decision is to be made regarding the feasibility of developing a special education program for students below 80 IQ, there are two basic approaches to making such a decision (1) The decision can be made on the basis that the need exists A solution to the problem is desirable on the part of the school officials, the community, and of course the students involved The question is should the necessary funds be committed to provide facilities and staff and supporting personnel to initiate the program in special education A judgment could be made on the basis of whether or not the necessary funds are available to implement the program An alternative way of making the decision as to whether or not the program is to be implemented is based upon a comprehensive look at the functions of the system The amount of resources are being put into the system functions in terms of dollars, staff, and facilities Comparisons are made regarding the investment of resources in the special education program relative to the other functions On the basis of definitive information regarding current allocation of resources, a decision can be reached as to whether or not a reallocation of resources should be made in order that the special education program can be implemented

If decisions are made on the basis of the reallocation of resources, it becomes quite clear to the decision maker that if he is to put resources into a venture, those resources must be transferred from some other function In this sense then there is a cost function involved in the decision making that extends beyond the mere dollar value of the monies involved The cost function must be calculated on the basis of comparisons of the new function with those functions which must be abandoned in order that the new function be implemented Cost analysis, therefore, becomes a somewhat more all-embracing term The concept of cost involves a combined term of cost utility rather

than merely the dollar value involved Effective costing, therefore, must be thought of in terms of cost utility analysis rather than the mere allocation of dollars Some clarification of this concept is possible if one thinks in terms of programming as a fixed utility approach, that is, you design your program around a set of priorities and preferences and allocate your resources strictly on the basis of fixed utility An alternative approach, also a fixed nature, would be that you plan your program from the approach of a fixed budget Probably neither of these approaches can be optimal, although the second approach, that is the fixed budget approach, is one used almost universally by budget planners in school systems That is, the budget is designed around the budget of the prior year with slight additions here and there, based upon what the superintendent believes the traffic will bear for the coming year A more nearly optimal approach involves combining the dollar amount available for the total budget and specifically spelling out utilities for the various subfunctions Various procedures have been systematically developed that allow the administrator considerable assistance in the area of costing These procedures are extremely valuable as a part of criteria for evaluating systems projects The terms which describe techniques helpful to costing include cost benefit analysis, cost utility, cost effectiveness, and many of the techniques developed in the area of systems analysis

Utility

The process of allocating resources is determined by the selection of certain courses of action from among various alternatives Which courses of action are selected will be a function of the relative utility or value of the different alternatives The ultimate criterion, therefore, is utility, value, or payoff to the system In this sense education is similar to business The return on investment represents the utility of a given function Inequities of operating a dual school system (Negro and white) exist not so much because the number of dollars put into each child is different but rather because for each dollar invested the expected educational outcomes are considerably different

The advisability of assigning a dollar return on investment is not always sound Many educational functions require an assignment of a numerical utility Perhaps this is done intuitively in most administrative decisions when selection from alternatives is made Formal systems work assumes a more rigorous assignment of a utility number

Time

Time dimension as an evaluative criterion is closely associated with effectiveness In terms of accomplishment one is required to look into the relative time requirements for two systems Time is particularly relevant in evaluating programs There is also a high correlation between time and cost In Chapter 6 on "Planning and Control" considerable attention is given to control of the time factor in management Techniques such as PERT have been designed specifically to furnish management with systematic control of time functions Allocation of resources is linked closely with time when implementation is the concern Much of the contribution of modern electronic data processing involves time Indeed the development of EDP was required because the immense volume of information could no longer be processed by manual procedures within reasonable time periods

Summary

An introduction to the basic concepts of systems analysis as applied to education has been given in this chapter A review of theoretical and historical background of systems concepts has been developed Considerable stress is placed upon the total systems concept as of primary importance Also considerable attention is directed to the necessity for continuous monitoring of the new system after it has been implemented

The closely related fields of systems and cybernetics have been discussed in terms of common etiology A general guideline is furnished for conducting and evaluating a systems study

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CHAPTER 3

Scientific Administration

Introduction

Scientific administration evolved through three rather clearly defined stages (1) efficiency methods, (2) management science, and (3) quantitative decision making All three stages of scientific administration were natural concomitants of the technological *Zeitgeist*

The emergence and widespread use of mechanization in industry necessitated efficient utilization of machinery Expansion of individual industrial enterprises required more formal procedures for planning and control Finally the advent of computers initiated applications of numerical control and extensive use of quantitative approaches to administrative decision making

Educational administration has not closely paralleled industrial and business management, however, it has become increasingly clear that modern technology will change profoundly the way in which schools are to be administered Use of computers for scheduling classes, advanced techniques for planning and control, technological advances in media, and mechanical and automated laboratory equipment all portend significant changes in how schools will be operated

Although scientific administration has generally been considered to be a twentieth century phenomenon, this is not necessarily so As early as the

third century B C in China, Han Fei Tzu established a set of management principles that were a synthesis of principles of laws, methods, and authority He attempted to build an analogue of governmental rules and regulations and apply that analogue to management terminology In this way it was thought that a systematic approach could be brought to management [1]

The essential ingredient in Han Fei Tzu's approach to management was that of systematic control through a set of clearly defined rules "The intelligent ruler unifies measures and weights, sets up different standards, and steadfastly maintains them, Therefore, his decrees are promulgated and the people follow them Laws are the models for the empire and the representative standards for all affairs "[2]

Some of Han Fei Tzu's concepts regarding organizational structure were comparable to the modern organizational structure of General Motors That is, the principle of decentralization was applied although central authority was maintained [3] In terms of Han Fei Tzu's principles, "When a subject makes claims, the ruler gives him work according to what he has claimed, but holds him wholly responsible for accomplishment corresponding to this work When the accomplishment corresponds to the the work, and the work corresponds to what the man claimed he could do, he is rewarded "[4]

Certainly the seeds of scientific methodology were present in the approaches to management espoused by Han Fie Tzu That is, systematic observations were made, records were kept, and replications tested the efficacy of the methods

Efficiency Methods

The work of Frederick Taylor marked the beginning of scientific admin istration Although the ideas of Taylor were primarily directed toward increasing the efficiency of the individual worker, Taylor's work proved to be the basis for much of scientific management as it is known today Taylor's work developed in the late 1800's A paper, 'A Piece Rate System," published in 1895, summarized his early work on rates

[1] Donald V Etz, The First Management Consultant?, *Management Review*, LIII (September, 1965), p 55

[2] *Ibid*, pp 55–56

[3] Alfred Sloan *My Years with General Motors* New York Doubleday and Company, 1964, p 50

[4] Etz, *op cit*, p 56

> (1) Wages should be paid to men and not to positions; (2) ratefixing should be based on accurate knowledge and not by guessing, (3) rates based on exact observation are more uniform and just, (4) with rates properly established, products are produced cheaper and workmen can earn higher wages than are usually paid, and (5) wages based on exact knowledge develop better workmen, remove motives for soldiering, permit the earning of higher wages, and create the basis for cooperation between management and men because of common interests [5]

Taylor was not concerned solely with efficiency methods of workers His concern for management was illustrated by the work published in 1903, *Shop Management*, in which he attempted to show the effects of wages and costs on managerial operations *Shop Management* was, in a sense, a primer for scientific management In addition to emphasizing methods, consideration was given to worker motivation and to organizational structure Taylor's preoccupation with total management was shown in *Principles of Scientific Management*, which was published in 1911 Three objectives were stated in the book

> (1) To point out the great loss that the country was suffering through inefficiency in most daily acts, (2) to try to convince the readers that the remedy for the inefficiency lay in systematic management , (3) to prove that management was a true science, founded upon clearly defined laws, rules, and principles In addition, he proposed to show that the fundamental principles of scientific management were applicable to all kinds of human activities [6]

Harrington Emerson developed the first managerial consulting firm in America and invented the term "efficiency engineering" Earlier than most, he saw management problems in terms of organization and advocated the importance of staff guidance [7] Emerson's *The Twelve Principles of Efficiency* (1909) was one of the earliest and most comprehensive guides to good management His system gave a logical approach to the performance of managerial function, and his principles of efficiency provided further evidence that management functions can be identified, described, and differentiated from operation activities, systems, or techniques

[5] John Franklin Mee *A History of Twentieth Century Management Thought* Ann Arbor, Mich University Microfilms, 1959, pp 32–33

[6] *Ibid*, p 38

[7] "Famous Firsts High Priest of Efficiency," *Business Week*, No 1764 (June 22, 1963), p 100

Alexander Hamilton Church was concerned with the total view of managerial functions "If a management is going to be concerned with the total efficiency of the firm, it cannot be exclusively concerned with the efficiency of the parts "[8]

Church stipulated several requirements to improve the managerial function (1) information and (2) better managerial personnel He concluded that the two basic components in the conduct of business were the determinative and administrative factors [9]

Church contributed to the science of management by emphasizing facts and principles However, little recognition was given Church because his ideas did not offer immediate or concrete steps to decrease costs or increase profits

The Gilbreths, Frank and Lillian, contributed to the development of management science through integration of management and the social sciences Both Gilbreths advocated the cross fertilization of ideas from economists, sociologists, psychologists, and management specialists

Frank Gilbreth pioneered motion study by use of the laboratory method His methods for studying work were the foundation for the "method of synthetic standards" His studies helped determine the best elements of a motion cycle by developing methods of least waste Gilbreth's contribution to scientific management was primarily in the scientific approach to the analysis of work He remained pragmatic in his approach to time and motion studies

The Primer of Scientific Management was published by Gilbreth in 1914 The book presented scientific management in Socratic fashion and covered such topics as time and motion study and wage payment plans

Lillian Gilbreth, although interested in management organization and operations, was concerned primarily with fatigue and monotony *Psychology of Management*, published in 1914, presented the psychological aspects of management as (1) individuality, (2) functionalization, (3) measurement, (4) analysis and synthesis, (5) standardization, (6) records and programs, (7) teaching, (8) incentives, and (9) welfare [10]

Lillian Gilbreth's philosophy regarding scientific management stipulated that industrial harmony could be achieved by optimizing the placement of workers In this respect scientific management extended beyond the

[8] Joseph A Litterer, "Alexander Hamilton Church and the Development of Modern Management," *Business History Review*, XXXV (1961), p 222

[9] *Ibid*, p 213

[10] Mee, *op cit*, p 55

immediate efficiency methods and embraced the psychological aspects of the workers involvement Although much of the management function was in fact psychological, the difficulties involved in establishing scientific principles of management based upon psychology precluded a systematic psychological approach to management

Management Science

Henri Fayol was a major contributor to the development of management as a science Where Taylor approached the study of management from the operations level, Fayol was concerned with general management He was the first authority in the field to consider the teaching of management important [11] The assumption that the principles of management could be taught was based upon the fact that those principles could be tested and replicated, the two important characteristics of science

Fayol's *General and Industrial Management* was published in 1916 and translated into English in 1929 This was one of the first indicants that the Europeans were also concerned with scientific management and that a scientific approach to management was not the exclusive domain of American industrial efficiency procedure [12]

Fayol saw all organizations as requiring management and all of them as observing the same general principles He formulated the following fourteen principles in order to give guidance to the managerial function (1) division of work, (2) authority, (3) discipline, (4) unity of command, (5) unity of management, (6) subordination of individual interests to the general interest, (7) remuneration, (8) centralization, (9) scalar chain, (10) order, (11) equity, (12) stability of tenure for personnel, (13) initiative, (14) esprit de corps [13]

Fayol developed a modern management philosophy He believed that "better management depended upon better management training at the top"[14] In the present age of industrial technology this principle of management training is exemplified in such large corporations as International Business Machines, which has one of the most efficient and widespread

[11] *Ibid*, p 56

[12] 'Famous Firsts Discoveries from Looking Inward," *Business Week*, No 1814 (June 6, 1964), p 152.

[13] Mee, *op cit*, pp 58–59

[14] 'Famous Firsts Discoveries from Looking Inward," *Business Week*, No 1814 (June 6, 1964), p 154

training programs in existence Continuing support of that program attests to its payoff to the company

Henry L Gantt became interested in scientific management when in 1887, he joined Frederick Taylor in his experiments to raise productivity and decrease costs at Midvale Steel Works in Philadelphia [15] His major contributions to scientific management were the Gantt Chart, the task and bonus plan, and several concepts dealing with industrial leadership Gantt's most enduring concept was that of the chart

The Gantt Chart showed equal divisions of space in a single horizontal line and at the same time showed (1) equal division of time, (2) varying amounts of work scheduled and (3) varying amounts of work done [16] Gantt's chart represented a forerunner to more systematic planning and control In a very real sense the chart laid the groundwork for the development of the Program Evaluation and Review Technique, PERT, which has gained widespread use in the military as well as private industry

Many persons and many disciplines contributed to the emerging scientific attitude toward management Along with the growing sensitivity to the needs of a more quantitative approach for executive decision making, the social sciences contributed also to an understanding of the dynamics of human relations The new social psychology of the twenties was emerging at about the same time that emphasis was being given to a more systematic approach to management decision making

The papers of Mary Parker Follet published under the title *Dynamic Administration* illustrated the concern for better human relations as an essential part of modern management Follet's concern with group dynamics helped to initiate many later studies in group interaction Specifically those studies were concerned with group interaction as they applied to executive decision making [17] Although human relations in group dynamics were a major concern of Follet, this should not be construed to mean that she was concerned only with behavioral studies Her concern was primarily with the management process An encapsulated view of her management philosophy indicated her concern about bringing the various behavioral sciences to focus on the single problem of management operation Illustrative of her concern was "the law

[15] "Famous Firsts Charting a Way to 'Democracy'," *Business Week*, No 1793 (January 11, 1964), p 44

[16] Mee, *op cit*, p 65

[17] "Famous Firsts Sibyl of a Modern Science,' *Business Week*, No 1838 (November 21, 1964), pp 196 and 198

of the situation, significance of management training and development, the application of behavioral science to problems of organization, constructive uses of conflicts, psychology of power, nature of horizontal communication and multiple management and social responsibilities of management "[18]

At the onset of the twentieth century, alert managers were sensitive to the work being carried on by Taylor and others Engineers who had gone the management route were vitally interested in the more quantitative scientific approach to management decisions The new movement began to display "characteristics of continuity and literary self-consciousness, and for a decade maintained a distinct identity relatively little affected by other industries "[19]

Management's growing concern with a more scientific approach to administrative decisions also had an impact upon labor relations The concern was that a new depersonalized approach to management would have an adverse effect upon the employees However, the new efficiency methods in management caused benefits to be derived for the employees as well as for the company Between 1900 and 1916, such labor innovations were initiated as the institution of employee welfare work, establishment of many fringe benefits, increased attention to employee safety, and more efficient working methods due to scientific management [20]

Newer concepts of management represented only one facet of the emerging science and technology The scientific approach to product development became evident about the same time that interest was aroused in scientific principles of management The first industrial research laboratory in the United States was established by Thomas Edison at West Orange, New Jersey, in 1887 This industrial research laboratory was considered to be an extension of management and was developed specifically under the aegis of management organization and control In this fashion the research laboratory became an instrument of management policy Random development of a product was no longer adequate Bringing the research activity and product development under direct control of management assured continuity of program research, development, and distribution [21]

[18] *Ibid*, p 32

[19] Leland H Jenks, "Early Phases of the Management Movement," *Administrative Science Quarterly*, V (December, 1960), p 427

[20] Norman J Wood, "Industrial Relations Policies of American Management," *Business History Review*, XXXIV (1960), pp 404–405

[21] Louis Marshall, "Pioneers of Management Industrial Research," *Advanced Management Office Executive*, II (February, 1963), p 30

In 1900, Willis R Whitney founded the first research establishment to "devote a substantial portion of its activities to pure basic research aimed at the establishment of fundamental principles "[22] Although Whitney's laboratory was designed for basic research, it set the theme for later developement of industrial laboratories by fostering basic work but emphasizing long range applications and product development In this sense it set the pattern for present-day industrial research and development centers Such centers supported basic research, but in so far as management was concerned, long range justification for basic research was product development

In 1911, the Amos Tuck School of Administration and Finance at Dartmouth College held the first conference on scientific management In April of the same year, a section of the Congress of Technology was devoted to the areas of administration and management [23] Emergence of Operations Research reflected this same impetus given to management when basic scientists began to feel that the study of administration was a respectable way to occupy one's time

During the 1920's Western Electric Company undertook a study to determine the effect of working conditions, the length of working days, and the number and length of rest pauses on worker output Six girls were placed in a special room under one supervisor The introduction of each new incentive raised production The girls developed very high morale and became extremely motivated to work hard and well because they had been singled out, had freedom to set the work pace, and had social contact Upon return to their original working conditions they did not drop to former levels but continued to improve Better morale was the result of management's being interested in workers as persons [24]

This research established that "motivation to work, productivity, and quality of work all are related to the nature of the *social* relations among the workers and between the workers and their boss "[25] The emphasis of social and personal relationships as prime forces in motivating output were expanded and developed The foundation for many of the personnel-oriented approaches to management that were so widespread during the 1940's was set [26]

[22] *Ibid*, p 32 [23] Mee, *op cit*, p 65

[24] Edgar H Schein *Organizational Psychology* (Englewood Cliffs, N.J Prentice-Hall, 1965), pp 27–28

[25] *Ibid*, p 28

[26] John G Hutchinson *Organizations Theory and Classical Concepts* New York Holt, Rinehart and Winston, 1967, p 9

In the 1930's when economic and industrial conditions began to change, management thought followed and became oriented around the concepts related to organization systems and executive control in relation to production There was a growing concern about the general approach to organization with developing interest in management functions The economic and industrial climate of the decade provided a challenge to those responsible for management of enterprises in the economy although this was reflected very little in the trend of management thought [27] By the middle of the 1930's, however, there were indications of a trend in management thought toward the treatment of functions of executive leadership and management

Ordway Tead considered executive work and leadership to have much similarity He believed that leadership was only as strong as the objectives were sound and that it was important for leaders in industry to accept responsibility for setting proper objectives Tead emphasized the role of decisiveness in executive leadership He advocated the scientific method as the best approach to making executive decisions His emphasis upon proper decision making and his concepts of leadership, executive work, and decision making contributed to present day management thought [28]

Executive decision making occupies a major portion of the training of the present day executive Illustrative of this concept are the many simulation laboratories that have been developed in graduate schools of business around the country This is not at all surprising since the central role of the administrator is that of a decision maker

The work of Chester Barnard indicated the modern approach to management His approach to management was analytical and dynamic He emphasized communication responsibilities of executives, investigated the role of status in organizational endeavor, and developed a systematic analysis of incentive systems in organizations [29] His work functions of the executive presented a case for a psychosociological approach to managerial organizations and functions Barnard put heavy stress on the contribution of executive capacity and leadership for giving impetus and direction to cooperative enterprise He emphasized the psychological necessity for cooperative leadership to stimulate creativity and to maximize human effort [30]

[27] Mee, *op cit*, p 202

[28] Ordway Tead *Art of Leadership* New York McGraw-Hill Book Company, 1935, pp 53-54

[29] Julius E Eitington, "Pioneers of Management," *Advanced Management Office Executive*, II (January, 1963), p 18

[30] Mee, *op cit*, p 228

The work of Luther Gulick and L. Urwick reflected an emphasis upon sociological and psychological approaches to the study of administration. The joint editorship of Gulick and Urwick in a volume entitled *The Papers of the Science of Administration* illustrated this point of view.[31] Urwick's concept of administration was pragmatic. He considered such practical things as forecasting, planning, organization, and control as being the primary ingredients of administrative operation. The contributions of Gulick and Urwick were primarily in dissemination of scientific principles of administration rather than basic contributions to fundamental knowledge in the field. In this sense they furthered the cause of a new approach to administrative training. The names of the two men were usually linked in the literature primarily because of the co-editorship of papers on the science of administration. Although both men were concerned with the same basic problems in administration, each contributed to the literature in his own right.

Herbert A. Simon's contribution to administrative science lay in the areas of organization structure and administrative decision making. His organizational theory of decision making classified the decision-making process according to the type of decision made: (1) innovative—occurred in circumstances that were new and called for new decisions, (2) routine—programmed or standard operating procedure.

Innovative decisions call for creative approaches to solutions and are the more difficult to study. Routine decisons follow a rational choice model. Because they adhere to classical, predictable processes, routine decisions are subject to investigation by means of computer simulation and mathematical modeling.

Simon indicated two distinct processes associated with administrative decision making. One involved the psychological and intellectual behavioral repertoire of the individual, and the other involved the many intricacies of the organizational structure. Therefore, any administrative decision involved the talents and experiences of the individual decision maker operating within the context of the many dynamic human interrelationships that comprised the organization.

Administrative behavior has as its central objective the coordination of many dynamic organizational relationships. As Simon has suggested, it illustrates the vast importance of the elemental device of putting a large number of people at work on small tasks identified by subdividing large, collective objectives.

[31] Sterling D. Spero, "Pioneers of Management," *Advanced Management Office Executive*, I (December, 1962), p. 25.

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[30] Mee, *op cit*, p 228

The work of Luther Gulick and L Urwick reflected an emphasis upon sociological and psychological approaches to the study of administration The joint editorship of Gulick and Urwick in a volume entitled *The Papers of the Science of Administration* illustrated this point of view [31] Urwick's concept of administration was pragmatic He considered such practical things as forecasting, planning, organization, and control as being the primary ingredients of administrative operation The contributions of Gulick and Urwick were primarily in dissemination of scientific principles of administration rather than basic contributions to fundamental knowledge in the field In this sense they furthered the cause of a new approach to administrative training The names of the two men were usually linked in the literature primarily because of the co-editorship of papers on the science of administration Although both men were concerned with the same basic problems in administration, each contributed to the literature in his own right

Herbert A Simon's contribution to administrative science lay in the areas of organization structure and administrative decision making His organizational theory of decision making classified the decision-making process according to the type of decision made (1) innovative—occurred in circumstances that were new and called for new decisions, (2) routine—programmed or standard operating procedure

Innovative decisions call for creative approaches to solutions and are the more difficult to study Routine decisons follow a rational choice model Because they adhere to classical, predictable processes, routine decisions are subject to investigation by means of computer simulation and mathematical modeling

Simon indicated two distinct processes associated with administrative decision making One involved the psychological and intellectual behavioral repertoire of the individual, and the other involved the many intricacies of the organizational structure Therefore, any administrative decision involved the talents and experiences of the individual decision maker operating within the context of the many dynamic human interrelationships that comprised the organization

Administrative behavior has as its central objective the coordination of many dynamic organizational relationships As Simon has suggested, it illustrates the vast importance of the elemental device of putting a large number of people at work on small tasks identified by subdividing large collective objectives

[31] Sterling D Spero, "Pioneers of Management," *Advanced Management Office Executive*, I (December, 1962), p 25

Executive decision making involves selecting optimal alternatives at many choice points Unfortunately not all alternatives can be selected on quantitative bases All decision making includes at least two kinds of symbolic phenomena, fact and value These symbolic phenomena are imbedded within the social system and must be extricated by the executive decision maker [32]

The influence of the organizational structure and the circuitous route of decisions has been stated by Simon as (1) the organization largely determines to whom one talks, (2) to whom one talks is largely determined by what one thinks and (3) how one thinks is largely determined by the organization These principles hold only in so far as decisions regarding the organization are concerned

Mee has summarized Simon's philosophy as the first comprehensive treatment of decision making as a distinct activity Provisions of basic concepts and the framework for decision making facilitated development of quantitative techniques for decision making in the 1950's Simon's concepts and beliefs within administration involved processes and methods for taking action toward goals Hierarchy of decisions existed in keeping with the hierarchy of authority in the downward levels of organization Decision making must be considered in reference to fact and value, rationality in administrative behavior, the role of authority, the criterion of efficiency and the psychology of administrative decisions Three general steps were included in the decision making process (1) identification of alternative strategies, (2) determination of consequences, and (3) relative comparison of each strategy [33]

Quantitative Approaches to Administration

Late in the seventeenth century, a French nobelman, Chevalier de Méré, addressed to the famous mathematician Pascal a question concerning a certain game of dice The game consisted of 24 throws of a pair of dice One could bet even money either on the occurrence of at least one "double six" in the course of the 24 throws or against it Some theoretical considerations led de Méré to believe that betting on the "double six" is advantageous On the other hand, the nobelman's empirical trials seemed to contradict this conclusion

[32] William J Gore *Administrative Decision Making A Heuristic Model* New York John Wiley & Sons, 1964, pp 67–68

[33] Mee, *op cit*, pp 256–258

The answer of Pascal was Given that the dice are "fair," that is to say, given that each die falls with equal frequency on each of its sides, the relative frequency of games with at least one "double six" is 491 Thus it appears that Chevalier de Méré's empirical research, rather than his theoretical analysis, was correct [34]

This quotation is characteristic of most quantitative approaches to administrative problems That is, applications of mathematics are made to practical administrative decisions Although quantitative approaches to administrative problems have been used for several hundred years, only during the present century has any substantial work been done that has made a contribution to practical administrative operations

Early systematic work took place in the area of statistical decision theory The work of Karl Pearson and R A Fisher marked the beginning of a shift from descriptive statistics to analytical statistical decision theory Instead of making mere counts or enumerations of frequencies, a growing emphasis was placed upon the interactions of variables and the more dynamic aspects of the problems

Perhaps contributing to this more analytical approach in statistical work was a changing theoretical structure in physics Nuclear physics produced the necessity to study physical problems under probabilistic conditions This required a more sophisticated statistical technology than had been previously available and brought the scientist into statistical work Interaction of these two factors, analytical techniques and scientific rigor, laid the foundation for the development of more quantitative approaches to administrative problems in general Techniques became more sophisticated as more sophisticated persons became interested in administrative problems

About the time of World War II a set of techniques that now fall under the umbrella of operations research attracted much interest British scientists had developed radar, but the military were uncertain about how it might best be used Enlisting the aid of the men who had designed the equipment, operating data were carefully collected and analyzed with mathematical and numerical techniques A theory was developed and used to make predictions about future operations

It was estimated that British power in air defense during the "Battle of Britain" increased tenfold This success caused the military to organize other teams of scientists to study other problems of weapon use, tactics and strategy

[34] J Neyman *First Course in Probability and Statistics* New York Henry Holt and Company, 1950, p 4

The success of these teams contributed improved methods of search for submarines, better arrangements for convoys, methods for achieving better aerial bombing accuracy and appropriate tactics in the face of Kamikaze attacks[35]

Operations Research started in the Army through the fact that antiaircraft gunnery was an army assignment Antiaircraft Command was under operational control of Fighter Command in the Royal Air Force The G L Mark I equipment used to determine the bearing and slant range of an attacking bomber did not give the elevation of attacking aircraft This information was provided by a sound-locating apparatus, resulting in a very cumbersome combination that seldom worked The OR system, nevertheless, increased the efficiency and decreased the fatigue of the gun crews through the analysis of operations[36]

Radar apparatus, working perfectly in a testing laboratory, often failed to work properly on a specific site where it was erected Radar gun sights were too temperamental to be checked like ordinary gun-sights In September of 1940, Blackett brought together men with good scientific training but no knowledge of specialized radio These men suggested that the ground near the radar receiver be covered with mats of wire netting to provide a level uniformly conducting artificial ground surface Blackett's Circus was frequently on the gun-sites during night attacks and studied data on tactics systematically[37]

At the beginning of the war, Coastal Command air attacks on submarines were disappointingly unsuccessful The 450-pound depth charges were followed with a 250-pound design that could be safely dropped from low heights, but little success was obtained A study of the operation revealed that the charges set to explode at depths of 50 to 150 feet were far too deep A setting of 100 feet was recommended The operations researchers investigating what actually happened soon calculated that the best setting for exploding the depth charge was probably 25 feet But the mechanism for detonating the standard depth charges could not be set for depths more shallow than 35 feet Unable to do better, the researchers advised setting the charges to explode at 35 feet The number of submarines sunk or killed in proportion to air attacks went up from two to four Soon a 25-foot setting on depth charges was designed, and prisoners taken from sunken submarines told interrogators

[35] J G Crowther and R Whiddington *Science at War* New York Philosophical Library, 1948, pp 91-92
[36] *Ibid*, p 95
[37] *Ibid*, p 96

they believed that the amount of explosive in the depth charges had been doubled and that this caused the increase in sinkings [38]

Dr H R Hulme and Mr J H C Whitehead applied OR to sailing convoys and their escorts In 1942, when U-boats mass-attacked the convoys, the convoys were liable to heavy losses Dr Hulme and Mr Whitehead suggested the convoys travel in larger numbers This position resembled that of a man out duck shooting "If a flock of eighty duck fly over him, he will not be able to shoot down any more than if a flock of only forty birds fly over, for he will be able to fire only the same number of shots in both cases He will not have time to re-load"[39] They suggested reducing the number of close-escort groups Hence, the chance of an attacked convoy receiving relief from a support group of escorts would be approximately trebled

The Operational Research Section of Bomber Command investigated the causes of bomber losses by analyzing attacks on Cologne and Frankfurt For operations in moonlight and in the dark they investigated the number of aircraft used in a given area, and the results led to the introduction of the 1,000-bomber raids The fear of collisions between the bombers caused the OR Section to forecast that on an average only one bomber would be lost through collision in such a raid In the first 1,000-bomber raid on Cologne, one plane was lost by collision [40]

The Army OR Group investigated the effects of variations in pressure required to operate the trigger on the accuracy of aim from a stationary tank shooting at a moving object The target, a two and a-half-foot-square board mounted on a scout car, was run along the road at steady speeds of 10 miles per hour and 20 miles per hour and at a variable speed from 10 to 20 miles per hour Working with dummy ammunition, the gunner loaded, aimed and fired the gun while a camera (securely attached to the gun barrel) recorded the accuracy of aiming Pressure required to release the firing mechanism varied from 25 pounds to 65 pounds, and two methods of aiming (following and laying ahead) were used Experimental figures proved that an increase in the load required to work the trigger caused a decrease in accuracy of horizontal aim when firing at a moving object, but errors in elevation aim were not increased with extra trigger pressure The OR Group recommended that it would be essential, if moving targets were to be aimed at accurately, to keep trigger loads of guns as low as possible and not in any case exceed

[38] *Ibid*, pp 99–100
[39] *Ibid*, p 101
[40] *Ibid*, p 106

In spite of the reluctance on the part of many administrators toward making quantitative decisions, the growing complexity of present-day school systems demands more sophisticated decision making than that customarily applied

The history of widespread use of Operations Research by major industrial organizations suggests that educational administrators will utilize these techniques as the complexity of school systems increases In larger systems and in several educational administration departments, there is already increasing evidence of interest and activity

As noted, the complexity of military organizations has necessitated reliance upon more sophisticated procedures for decision making

> If there are thousands of choices from which particular weapons systems can be chosen, the executive is faced with a cruel dilemma having to choose from among the tempting array which he must pay for with limited resources, raw materials, manpower, time and energy Presumably he should choose the best buy, but this can hardly be done by the non-technical executive only with the aid of intuition as in earlier times What he is usually forced to do is have staff studies or systems analysis or operations research made which will narrow down the choices to a manageable few [46]

Flagle's reference to an array of alternative actions with limited resources suggests the central theme of Operations Research That theme involves the optimal allocation of resources within the constraints of limited resources

The term *optional allocation of resources* proposes that the total system is to be taken into consideration A *total system* assumes that all of the various components are interacting in such fashion that the system is an integrated assemblage

The superintendent is concerned with a school system that functions within this definition of a system However, operationally, not many school systems function as a total system Individual schools operate almost autonomously in many systems Major budgetary functions are uncoordinated and curriculum projects are not appropriately weighed

In any system study it is imperative that the total system be considered "It is the essence of operations research that it be applied directly to making decisions affecting the management of ongoing businesses In other words it forms the basis for executive decisions"[47]

[46] *Ibid*, p 43

[47] R T Eddison, K Pennycuick, and B H P Rivett *Operational Research in Management* New York John Wiley & Sons, 1962, p 25

In operations research models are used to help make decisions since operations research problems are generally decision problems There is some ultimate objective in that the decision maker wants to maximize (or minimize) the model then used to find the effect of various alternatives on the objective, thus helping in making the decision[50]

There is a tendency for many administrators to assume that the application of operations research to school systems always presumes extremely sophisticated quantitative techniques This is not always true The real contribution of operations research to school problems rests with the scientific frame of reference that one brings to school problems

> Operations research has established itself as an activity that can and does bring new attitudes and new concepts and new techniques and research into the service of management And with each passing day it is increasing the capability of helping management to solve more complex action problems to make major decisions[51]

The basic scientific attitude toward problem solving plus quantitative orientation takes much of the guesswork out of administrative decision making The simplicity of the solutions to many problems has caused some to refer to operations research as systematic common sense This has been illustrated by the solution of many military problems

> An operations research worker during his first day of assignment to a new field command noticed that there was considerable delay caused by the soldiers having to wait in line to wash and rinse their mess kits after eating There were four tubs, two for washing, two for rinsing The operations research worker noticed that on the average it took three times as long for the soldier to wash his kit as it did for him to rinse it He suggested that instead of there being two tubs for washing and two for rinsing there should be three tubs for washing and one for rinsing This change was made and the line of waiting soldiers did not merely diminish in size but most days no waiting line ever formed[52]

The anecdote above, although of extreme simplicity, illustrates well the contribution of operations research that concentrates upon operations rather

[50] Flagle, *op cit*, p 176

[51] Joseph F McCloskey and Florence N Trefethen, editors *Operations Research for Management* Baltimore The Johns Hopkins Press, 1956, p 11

[52] Morse, *op cit*, p 3

Reference has been made several times to the terms *operations research* and *systems analysis* as if the two terms were synonymous This is, however, not strictly the case The application of science to the design of mechanical and man-machine systems is sometimes called systems analysis, and this is often equated with operations research In general, the term systems analysis denotes man-machine systems The term operations research does not embrace hardware but is concerned exclusively with operations

The contribution of operations research has been primarily in increased effectiveness of available resources without the use of additional resources There are many illustrations of this

> Taylor's work has been followed by a number of other impressive aids to managerial decision making by the development of accounting techniques, by Gantt's charts, Gilbreth's micromotion studies, Shewhart's statistical quality control, by the emergence of aptitude tests, and, in a somewhat more qualitative sense, by the dramatic Hawthorne Experiments [48]

As indicated earlier, it is not always possible to quantify educational administrative operations In addition to the nature of operations, there are time and talent problems that preclude strictly quantitative analysis of educational problems

> Research should be organized to take advantage of the continuing nature of managerial decision making The absolute necessity of this is obvious when it is remembered and it cannot be too often stressed that the executive has to make decisions on the best information available to him at the time He cannot postpone them until the perfect answer is available although one of his frequent types of decisions is whether to act now on the information available or wait in hope of better [49]

Requirements for quick decisions have complicated the modern educational administrator's life As school systems increase in size and complexity, the administrator becomes further removed from the source of information Fortunately the use of computers as total information systems is beginning to solve this problem The use of computers also allows the present-day administrator to solve many of his problems by simulation and building models

[48] Flagle, *op cit*, p 19
[49] Eddison, *op cit*, p 28

scheduling, optimum allocation of educational resources, military resource allocation, building programs and many others [54]

Game theory is a mathematical approach to decision making designed to assure that each opponent will minimize his losses and maximize his gains under the given set of circumstances [55] The basic paradigm of the theory of games is a matrix model set up to define strategies or rules of the games that should most appropriately be applied in a conflict situation Most game models consist of two-person games the two persons being defined as opposing sides Possibly a clearer description is two interest games

The basic model consists of one individual opposed to another, or of one individual opposed to five hundred individuals The fundamental game matrix considers this to be two persons with opposing interests Such conflicts may be between a superintendent and the board, between a principal and the teachers, between a teacher and the students, between professional educators and the community, or many other types of conflict situations where the basic game stipulates that one side wins and another loses Much of present military strategy is based upon game theory Although the practical payoff has been relatively low, a study of the theory of games contributes much to an understanding of the basic decision process [56] It also illustrates how one can assign quantitative values to what appear to be qualitative matters In essence, game theory is concerned with the basic conflict situation where certain strategies are available to each opponent and clear-cut rules of the game are stipulated The objective for each opponent is to maximize his gains and minimize his losses under the circumstances

Inventory control represents one of the more widely used techniques in the quantitative areas of decision making [57] Although its use is probably somewhat restricted in educational areas (other than large systems requiring considerable amounts of inventory items), the technique has furnished manufacturing operations with measureable and considerable improvement The central features of the inventory model consist in optimizing the number of inventory items to be ordered at any particular time and in optimizing the time factor between orders In this fashion, adequate inventory is maintained

[54] Robert W Llewellyn *Linear Programming* New York Holt, Rinehart and Winston 1964, pp 1–6

[55] J C C McKinsey *Introduction to the Theory of Games* New York McGraw-Hill Book Company, 1952, pp 1–6

[56] M Dresher, L S Shapley, and A W Tucker, editors *Advances in Game Theory* Princeton, N J Princeton University Press, 1964, pp 1–27

[57] Eddison, *op cit*, pp 44–93

than equipment The same four tubs were used before and after the analysis, but the waiting line was eliminated

A few of the relatively well-established techniques now available to the operations researcher and hence to the administrator include linear programming, game theory, queueing theory, inventory control and simulation Linear programming has been the most widely used of these quantitative techniques [53]

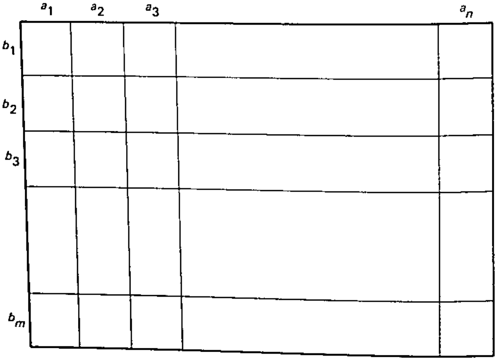

Figure 3 1. *Transportation matrix*

Assume that a certain number of ships are to be sent from each of n ports to fill the requirements at each of m destinations There are not enough ships at any given port to fill the requirements for the different destinations (Figure 3 1) The objective is to minimize the cost function and at the same time assure that the necessary requirements at the m destinations will be filled Variations of this basic model have been applied to many other situations Some typical applications include mixture problems that involve certain amounts of X to be distributed on Y's The linear programming model has also been applied to such problems as personnel assignment, diet preparation, transportation, railroads, student assignment, student

[53] F Stansbury Stockton *Introduction to Linear Programming* Boston Allyn and Bacon, 1963, pp 1-7

with those techniques. However, allocation models represent only one aspect of the broad range of techniques of operations research. Wherever there is regularity or systematic recurrence of operations, quantitative approaches to administrative decision making become appropriate.

There is a difference between classical statistical techniques and those mathematical models commonly associated with operations research.[60] Statistical models assume random fluctuations and are, therefore, attempts to derive information from uncertainty. On the other hand, those situations requiring operations research techniques are usually associated with deterministic mathematics and hence probabilistic assumptions do not apply. This is not to say that operations researchers do not rely heavily upon statistical techniques. It is merely to emphasize that the subset of allocation associated with operations-research techniques usually assumes deterministic mathematics rather than probabilistic mathematics.

In general, attempts at quantification assume some type of model or representation of an actual situation.[61] The quantitative approach allows one to study the interrelatedness of many dynamic variables in a live system. Where one is concerned with an economic model, for example, a finite number of budgetary dollars and finite requirements, decisions can be made on a quantitative basis by using allocation models. Such models optimize the distribution of available funds. Allocation models assume not only a better solution but indeed the best solution under the given set of circumstances. Such allocation models have been widely used in military and governmental agencies where the allocation of resources is of considerable importance. The reference to military and governmental agencies is specifically noted here because they are operational rather than production agencies. They are analogous to school systems. School systems should begin using the particular models of operations research that are concerned with the allocation of resources.

The efficient operation of any system (military, business, governmental, or educational) is dependent to a considerable extent upon the appropriate allocation of human and physical resources. Applications of quantitative techniques to administrative decision making do not in general lend themselves to routine applications. This concept is illustrated in the development of inventory control systems where the development of the model cannot be

[60] Samuel Messick and Arthur H. Brayfield. *Decision and Choice*. New York: McGraw-Hill Book Company, 1964, pp. 27–34.

[61] Sidney Siegel, Alberta E. Siegel, Julia M. Andrews. *Choice, Strategy, and Utility*. New York: McGraw-Hill Book Company, 1964, pp. 3–16.

and the cost is minimized In essence, most inventory models attempt to take into consideration two primary cost factors (1) the factor associated with the administrative setup for ordering and handling inventory production and (2) the actual cost of maintaining items in inventory Therefore, one will want to keep each of these cost factors at a minimum, yet maintain an adequate supply for immediate needs

Queueing theory has evolved from the mathematical work in the communications area, primarily in connection with telephone companies There is a need in the communication field to minimize the number of busy signal tie ups and also to minimize the switching equipment required to have an efficient field operation Signal engineers with mathematical inclinations have done the primary exploratory work in queueing theory The principal generalization of queueing theory is in the area of waiting times [58]

Many businesses now use queueing theory as part of their day-by-day operations in such things as customer waiting lines, communication channels, arrival rates, and plane stacking problems Attempts at the use of queueing theory might have some promise of payoff in various areas of education where waiting times are prevalent lunch lines, recitation periods, and equipment demonstrations

One other quantitative technique that has grown in popularity during the past decade is the use of simulation [59] In more sophisticated simulation studies mathematical models are designed to describe certain training periods or training sessions Therefore, it is possible to simulate complex decision-making operations under conditions where the consequences are not economically catastrophic to the company In this way various ideas can be tested and the excitement of the real situation is inherent in the game The student of simulation is subjected to many of the stresses and strains of the real situation He is permitted to make mistakes without dire consequences to the company Considerable amount of work has been done in simulation in the field of education However, most of the simulation studies in education are not of the quantitative type but rather involve such things as in-basket techniques

The above discussion suggests that quantitative techniques have contributed most to operations using allocation models This is probably due to the fact that linear programming mathematics has been relatively well developed and a growing number of professsional persons have now become familiar

[58] Flagle, *op cit*, pp 311-322

[59] Joel M Kibbee, et al *Management Games A New Technique for Executive Development* New York Reinhold Publishing Corporation, 1961, p 3

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completely general Many assumptions have to be made before the model is appropriately applied As a general rule in the use of quantitative techniques in administrative decision making, the best approach is that of any good scientist The problem is observed under objective and systematic conditions, and the solution follows from these observations It is not always possible to design the situation in the same fashion that one does in a classical experiment One must deal with the changing dynamic system and develop a model (preferably of a mathematical nature) that will describe the system

From a team approach one gets inputs of different individuals and disciplines, and the tools for many disciplines focus upon the problem For this reason it is impossible to invoke some specific statistical technique built around the assumption that a careful type of laboratory experiment is being conducted Most statistical approaches to experimental data assume random fluctuation, whereas in most administrative decision-making situations, most of these are anything but random Therefore, quantitative approaches must to a great extent be based upon deterministic mathematics rather than probability theory Again wherever the assumption is made of repetitiveness involved in a system, quantitative techniques can be used, and mathematics of a deterministic type can be utilized

Summary

An attempt has been made in this chapter to trace the development of scientific administration through three stages First, efficiency methods associated with the work of Taylor and those persons with engineering backgrounds have been presented The second stage has been discussed in terms of more general principles of management science, and the discussion has centered upon the development of administration as an emerging discipline Finally, the quantitative approaches to administrative decision making have been considered These techniques have been discussed primarily from the point of view of operations research They include such things as linear programming, game theory, inventory control, and simulation The growing utilization of quantitative techniques by administrators in military, business and government suggest the increasing role that these techniques will play in teacher and administrative decision making The growing scientific orientation to administrative decision making confirms the fact that administration is indeed a discipline

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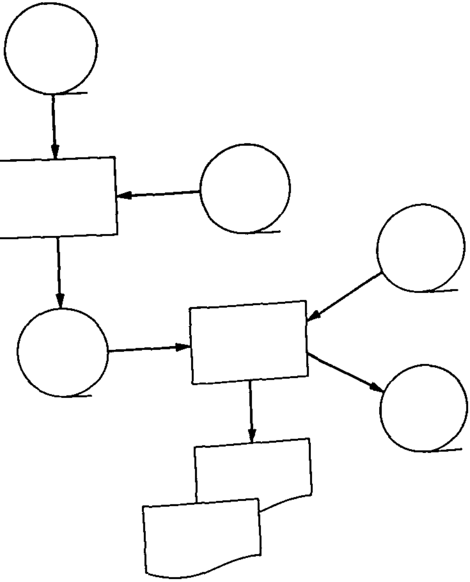
PART **TWO**

INFORMATION SYSTEMS



CHAPTER 4

Unified Management Information System

Introduction

Information systems are usually discussed primarily in terms of storage and retrieval of specific documents Indeed, the field has grown from the problems caused by the masses of paperwork associated with the publishing industry It has been estimated that the federal government alone produces approximately twenty-five billion pieces of paper per year and accumulates over a period of years enough records to fill 7 5 Pentagons—an investment approximating four billion dollars per year There are more than six million engineering drawings made annually by the military services, and it is estimated that there are fifty million drawings on file Somewhere in the neighborhood of seventy-five thousand new book titles are published each year In addition to books, there are approximately thirty thousand technical journals The contents of these journals approaches two million articles per year [1]

With the rapidly expanding information derived from research effort throughout the world, the volume of literature will continue its exponential rate of increase for the foreseeable future Obviously the traditional manual method of handling the tremendous volume needs considerable modification

[1] Charles P. Bourne *Methods of Information Handling* New York John Wiley & Sons, 1963, p 1.

system can be stored in the information system, making the information almost instantaneously obtainable to the administrator for day-by-day decisions In addition, a wealth of material will be available for simulation of many administrative decisions The constant flow of vital information with which the administrator plans and operates an effective school system is dependent upon the total information system

Information Systems for Management

Larger educational systems have been using electronic data processing equipment for some time on problems dealing with routine records, fiscal matters, and check writing However, the real breakthrough, the use of computers as part of the total information system, has not yet come in the educational field Many of the larger industrial corporations, however, are now using computers in ways that are far removed from the routine bookkeeping operation for which they were originally purchased

The Lockheed Aircraft Company is illustrative of the uses to which computers are now put In a real-time hookup, Lockheed has approximately fifty input and output devices Located throughout the area covered by the company, these input output devices are connected to computers Data are coming in constantly from multitudinous production operations that include job order details, location of various materials, and constant updating of inventory levels in various questions dealing with production Management has continuous control over all in-plant functions of manufacturing The system greatly enhances efficiency in purchasing production and inventory control It allows the company to make long-term plans concerning building utilization and personnel requirements [2]

The Wall Street Journal reports on the use of computers for overall information regarding agricultural activities in such things as the regulation of irrigation water flow, the appropriate selection and mix of fertilizers, the record keeping of farm animals The Performance Registry International, Denver, uses a computer for certifying animals [3]

The First National Bank of New York, as part of its management control, employs sixteen complete computer systems and hundreds of peripheral units to handle checking accounts and installation loans It can handle stock

[2] "Lockheed Management Information System (INTERLOC)," *Automation Reports*, No 44 (April, 22 1965), p 2

[3] "Computers for Farms—Present and Future," *Automation Reports*, No 45 (May 6, 1965), p 6

Accordingly, it is no surprise to see increases in activity toward automating information systems

Information Systems as used in this chapter will denote an extension of the concept beyond that associated with specific document storage and retrieval All types of information involved in organization and control of an educational system need to be included, therefore, emphasis will be placed upon a total systems concept Information systems as they assist in management and administrative control will be considered as well as the systems' organization, automation, and equipment

Total Systems Concept

The total systems concept implies concern for efficiency and interrelatedness of all components These components must act in coordination to produce an optimally effective system Functions of the subsystems have a direct bearing upon the total operations of the system The total systems concept as applied to information systems is involved with effective flow of information permitting a comprehensive and efficient system for decision making For effective decisions to be made in a school system, it is necessary for information to be available continuously regarding such things as achievement, personnel, inventory of the facilities, buildings and equipment—in short, all relevant information utilized in administrative decision making within the school system It should be not only accurate but should be also readily accessible to those in a decision making capacity

Information systems that deal with library facilities for storage and retrieval of specific documents are more restrictive than the systems being discussed here The technical capability is now in existence for automating university libraries, for instance, a user can request a subject-area search and receive a complete printout of available references

Applying this model to educational administration, one can readily see the utility of having continuous information available Answers to any question relevant to the operation of the system will be obtainable merely by interrogating the computer The information can be stored in such fashion that one can receive not only a comprehensive listing of factual data but also an analysis of data to assist in administrative decisions Within the central information system can be stored such information as curriculum offerings, student achievement, salaries, janitorial services, allocation of resources, projection of population of students, number of classrooms needed, budget, teachers, and administrative personnel A complete profile of the school

The Nuclear Division of Union Carbide has automated an information system that furnishes management with instant information for quick and sound decisions The Union Carbide Corporation in 1964, had two IBM 7090's, three 1401's, one CDC 1604, and two 160A's for research and development and also for production controls and business applications The system is used to provide comprehensive information for guidance in controlling costs and operations In addition to enhancing daily decision-making efficiency by a central information system, the long range planning of company objectives is a vital part of the total information system It furnishes the company with an economic barometer vital in assessing and planning operations [7]

These illustrations taken from industrial corporations exemplify the vital role which information systems are playing in modern management decision making Besides the quick and comprehensive accessibility to vital information, the validity of the information has greatly increased and sped the process toward a true management science As systems become larger, it becomes more and more apparent that greater reliance must be placed upon information systems The decision maker in larger organizations no longer has direct contact with his operations, and therefore, is dependent upon information flowing to his desk from another source Only through the use of modern technology can this continuous flow of information reach the decision maker at the appropriate time to be effective High speed equipment for storage, retrieval, and processing information coupled with newer mathematical concepts that permit an optimal amount of information to be abstracted have a vital role to play in administrative decision making Applications of this technology will result in quicker and better decisions on the part of the administrator In any management system there is no substitute for quick and valid information

Organization of Information Systems

The concept of information systems as a part of administrative or management structure has been emphasized Therefore, they should be included in the central administrative structure of the school system As a part of central administrative structure, the information system would be concerned with the continuous flow of information going throughout the school system and

[7] Hess Stringfield, Jr, "How Automation Aids Management," *Office*, LIX, No 1 (January, 1964), p 266

transfers, trust records, dividend distributions, and travelers' checks The complete system is handled on an international basis The data tapes are shuttled between Europe and New York As stated in the April, 1965, *Systems*,

> At the time items are posted to the Current Account Statement in Paris, punched paper tape containing the relative data of each transaction is produced as a by-product of the posting operation by attaching a punched paper tape unit to an NCR Post-Tronic bookkeeping machine The paper tape is accumulated for the entire month at which time it is mailed, together with the trial balance, to Park Avenue, New York There the paper tape is converted to magnetic tape and the data then processed Quarterly International Statements are prepared on a computer dispatch to the Paris Branch [4]

Westinghouse was the first large manufacturing corporation to identify the total system as an objective of information services Westinghouse had forty-seven general purpose digital computers in operation in 1960 Inventory control of all field and plant stock was stored on the computer New orders were teletyped to the computer center and fed into the machine The computer selected the right shipping point, sent out shipping instructions and updated records New telecomputers teletyped communications into the central information system This system imposed upon a corporation the size of Westinghouse was not without difficulties However, the system now is working effectively, giving "on line" organization information that furnishes overall guidance of budgetary management Operating in real time, field sales offices have direct access to the central unit for facts on delivery availability The center provides sales reports and other general tabulation on a daily basis A centralized information system moves decision making to higher management echelons [5]

General Electric has set up an automated operation to handle central information services that furnish managers with a more complete and earlier source of information required for rapid decision making The facility also allows for appropriate distribution of work station loads as well as handling routine things like billing [6]

[4] "First National City Bank A Special Report on Its Data Processing and Paperwork Systems," *Systems*, Vol VI, No 3 (April, 1965), p 32

[5] G J Evans, "Total Information Concept Guides Management Action," *Iron Age*, CLXXXIX, No 26 (June 28, 1962), pp 58–59

[6] Harold Strickland, Jr , "The Computer A Tool for Clerical Automation or Integrated Management Systems?," *Computers and Automation*, XII (April, 1963), p 27

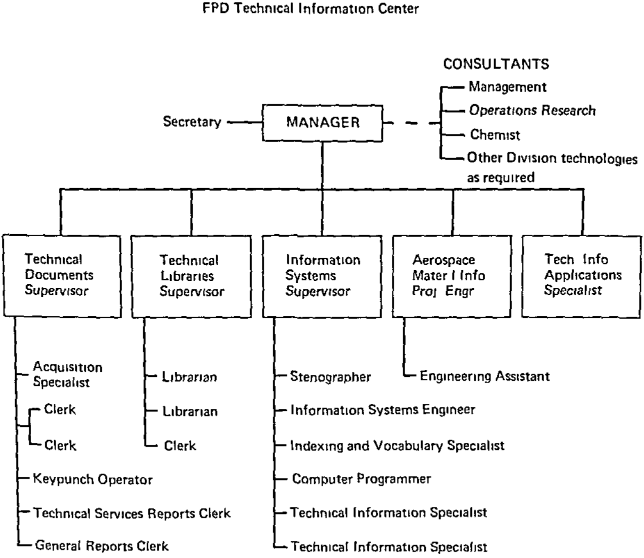


Figure 4 2 *Organizational structure of General Electric's Flight Propulsion Division* (Reprinted by permission of American Data Processing, Inc , Detroit, Mich , from *Information Retrieval Management,* Lowell Hattery and Edward McCormick editors, American Data Processing, Inc , 1962, p 69)

highest administrative level, information of the type that augments long-range planning in high-level decision making flows directly to the top administrative officer It is only through this type of organizational system that maximum use can be made of a total information system The organizational chart of General Electric's flight promotion division is designed to show the relationship of the information system to the primary users group The General Electrical system is designed principally as a resource unit serving the needs of the various divisions and is not specifically calculated to service top-management decision making The extent of the organizational structure and the personnel involved is shown in Figure 4 2

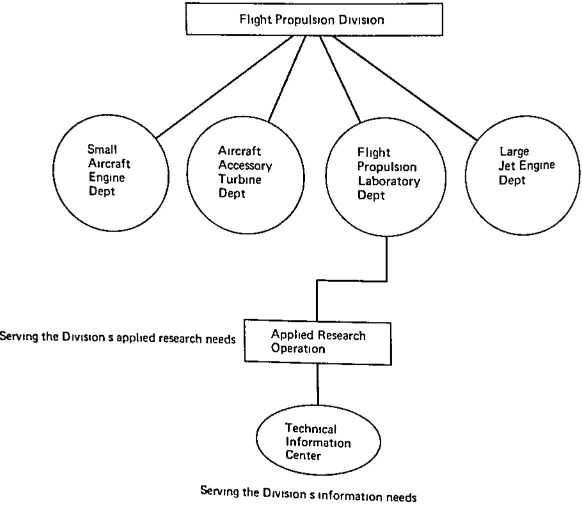


Figure 4 1. ***Organizational chart of General Electric's Flight Propulsion Division*** (Reprinted by permission of American Data Processing, Inc , Detroit, Mich from *Information Retrieval Management*, Lowell Hattery and Edward McCormick, editors, American Data Processing, Inc , 1962, p 68)

enhancing the decision making ability of the key administrator Defining information systems as part of the overall management function does not preclude the specific applications of information science to storage retrieval of documents, including library documents The discussion herein is an attempt to broaden the concept of information systems to include all "intelligence" regarding operations of the school system

The organizational chart shown in Figure 4 1 is designed to help put information systems in perspective within the total organizational system We can see that the information flow extends to different levels of administrative setup in the day-by-day operation of the school system However, at the

All human organizations have three essential features. (1) they have an objective or result to be achieved, (2) there are people, the implements by which the organization gets its work done and produces the results which are the reasons for its existence, (3) there is structure, the way people are placed in working relationships with each other For greatest effectiveness both the people and the structure of an organization must be well attuned to its objectives The information system is the attuning mechanism [8]

Technical Information Center
Operating Cost Breakdown — 1961

Salaries (Including Benefits)	55 7%	Per Cent of Total Cost
Acquisitions	5 6	
Data Processing	11 5	
Office Services	3 6	
Product Information	1 5	
Travel Living	1 2	
Telephone Telegraph	1 1	
All Other Variables	5 8	
Rent Depreciation Amortization	12 2	

Figure 4 3. *Operating cost breakdown for General Electric's information system, diagrammed in Fig 4 2* (Reprinted by permission of American Data Processing Inc , Detroit, Mich , from *Information Retrieval Management*, Lowell Hattery and Edward McCormick, editors, American Data Processing, Inc , 1962, p 71)

Automation of Information Services

Storage and retrieval of information has progressed through three stages The manual stage illustrated by the Royal McBee system is usually referred to as McBee cards This retrieval system entails a card with holes punched around the four edges To cipher a specific piece of information, one hole coded with that particular piece of information will be notched (Figure 4 4)

[8] Herman Limberg, "Organization and the Management Information System," *Office* LX, No 1 (1964), p 12

Figure 4 2 illustrates well the types of personnel involved in an information center This organizational chart might readily be superimposed as a part of top management rather than as a resource center for a specific division In determining costs for an information system like that at General Electric, Figure 4 3 gives an overall breakdown

If the system is really to function as an adjunct to top level administrative decision making, then the multifacets of the system must reflect specifically those sources of information which will be of greatest assistance to the decision maker One of the predominant problems involved in the organization of an information system is to retain the overall systems view in setting up the organization There is a tendency to be overly concerned with one of the components to the detriment of the overall system concept Specific statements of objectives as well as a comprehensive understanding of the interrelatedness of various components of the system are involved If the information system is to do real time monitoring of the multitudinous activities going on in a school system at a particular time, then the organization of the information system becomes rather clear The information system furnishes feedback to the decision maker regarding on going activities of the school system and is a substitute for directly observing the many activities of the school system

Although not specifically stated, this discussion has looked upon an information system as essentially an automated system utilizing electronic data-processing equipment and specifically employing electronic computers Such an installation within a school system assumes that the executives in that system have a new outlook toward problems in administration It assumes that a school system utilizing this type of facility reflects an administrative outlook that is consistent with the more progressive business corporations

There is always a certain amount of reluctance to adapt a new technology since adaptation assumes that the present procedures are not quite right Persons giving consideration to automated systems also have encountered a certain amount of inertia due to an inherent fear that the computer is somehow going to replace some key decision makers In practice this has not occurred If the system is adequately designed, the outcome in fact will be a more highly effective decision making procedure The decisions to be made are based upon rapid acquisition of more reliable information In so far as the key decision maker is concerned, there is no substitute for continuous, fast, and reliable information It is precisely this function that the information system is designed to fulfill

The interrelationships of the information system are summarized by Hershey who was quoted in "Organization and the Management Information System"

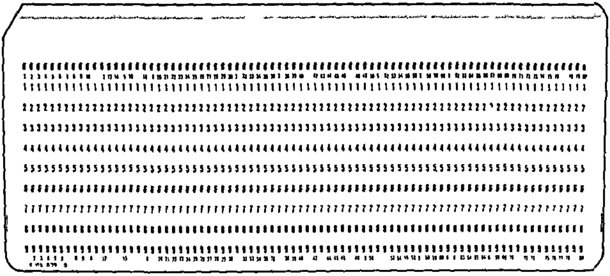


Figure 4.5. *IBM card*

The next step in the evolutionary process toward higher automated information retrieval systems is the utilization of computers where data can be stored on magnetic tape, cards, or disk packs In addition to the speed and flexibility of shifting from the noncomputerized automated system to the computerized system, one also has a tremendous increase in storage capacity Some magnetic tapes can store as many as fifty million digits per reel The speed of tape reading and writing ranges to a hundred thousand digits per second When one couples this high speed computer activity with the output devices giving printing outputs an access of five thousand lines per minute, one begins to appreciate the automated system of data storage and retrieval

The Armed Services Technical Information Agency (ASTIA), which has recently been renamed the Defense Documentation Center, is an example of an automated system. ASTIA allows the military documentation center to accept a request for bibliographic searches based on key words, for example, "the *assignment* of *personnel* by *linear programming* methods " The computer scans the entire system for intersection of those key words dealing with the assignment of personnel and linear programming Only those pieces of information that are relevant to the key words stipulated will be taken from the files Since ASTIA documents are stored by summary, the person making the request for a bibliographic search receives a comprehensive annotated bibliography over the time period requested In addition to performing the actual bibliographic search, the ASTIA system performs numerous administrative details such as checking on the inquiring person's eligibility to obtain information from the Defense Documentation Center

The system is semiautomated from the time of reception of request for

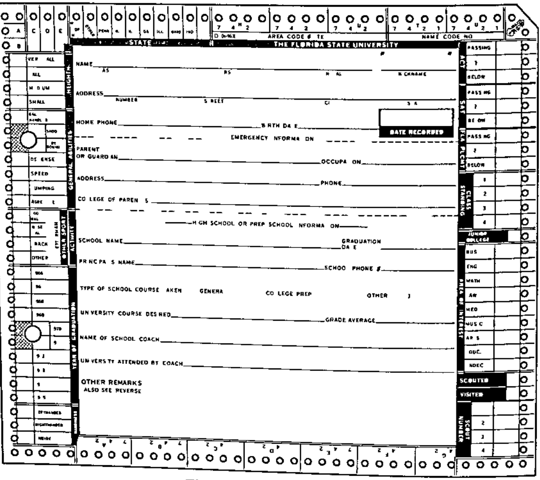


Figure 4.4. *McBee cards*

One can retrieve a particular bit of information by running a long needle through a hole in a stack of McBee cards and lifting the pile of cards Those cards with the coded notches drop out of the stack. In that way one has in fact retrieved those cards which have the particular characteristic under consideration Although the McBee card system is still used in many places where small amounts of information are needed for storage and retrieval, the system is inefficient when masses of data are to be handled.

The IBM card denotes a natural evolution from the earlier manual system By appropriate coding on the IBM punch card and with appropriate equipment for sensing where holes have been punched, one moves into the automated system of data storage and retrieval (Figure 4 5) The more elementary retrieval systems that utilize only the IBM card and appropriate sorter can search cards at the rate of approximately 450 per minute, thereby identifying the characteristics under consideration

easily extended by hooking into the National Medical Library, readily accessible to medical researchers throughout the country

As a final illustration of the necessity for automated information systems, one might cite L I Gutenmakher

> By 1955, 2,700,000 patents had been issued in the United States and twice as many in the rest of the world More than 60% of the time re quired by a patent examiner to issue a new patent is consumed in the search in the patent office
>
> In order to find any patent in the U S Patent Office, it is necessary to scan the accumulation of 1 to 10 million patents A survey of only 350 patents takes 4 to 6 manhours of skilled effort
>
> It was established that chemists spend 35% of their time in experimentation and nearly 50% of their productive time on information processes (searching of material, reading, writing reports, etc)
>
> The effective part of scientific work time is spent in selecting literature in order to obtain exhaustive information According to UNESCO data, the cost of searching for materials in U S libraries is $300,000,000 a year A Council on Library Resources capitalized at five million dollars was founded in Washington in 1956 to work on this problem
>
> In the Soviet Union there are several million engineers and approximately two hundred scientific workers If on an average, each required a complicated bibliographic reference only once a year, then in that year it would be necessary to issue 3 to 6 million references or 10 to 20 thou sand references per day Let us assume that the choice of specific information for one reference is derived from an average volume of a thousand pages of text per day, ten man days are needed to select the material for one reference and to fill all orders The effort of one to two hundred thousand qualified bibliographers is needed, examining the material according to the largest number of indexes The wages of these workers would involve many millions of rubles a year This problem can be solved only by the application of information systems [11]

Equipment for Information Systems

Figures 4 6 through 4 17 present examples of hardware associated with information retrieval systems Figures 4 6, 4 7, and 4 8 give typical complete information systems the NCR 315, RCA 70, and IBM 360 systems These three total systems include the essential ingredients in any information system

[11] L I Gutenmakher *Electronic Information Logic Machines*, translated by Allen Kent New York Interscience Publishers 1963, p 127

information through the assembly of the report to be sent to the person making the request The primary objective of the Defense Documentation Center is to implement an efficient exchange of scientific and technical information The documents stored at DDC come from the research contracts that are sponsored by the Federal Government Nearly 250,000 reports are indexed in a collection that consists of over 650,000 New reports are being received at the rate of about 30,000 titles per year Approximately 700,000 reports are sent to persons making bibliographic requests each year, and about 5,000 requests are received annually for searches of bibliographic material A UNIVAC 90 computer system was installed in early 1960 This system of hardware coupled with a comprehensive technical thesaurus greatly increases the efficiency of the Defence Documentation Center By the use of the system known as Uniterm, it is possible to handle efficiently the storage and retrieval of documents located at the DDC [9]

The National Library of Medicine has set up an automated system called MEDLARS, taken from the title *National Library of Medicine's Medical Literature Analysis and Retrieval System* Schiller reports the four general objectives of this particular system as being

> 1 to increase the coverage of all the substantive medical literature of the world, 2 to provide deeper subject analysis and broader accessibility to bibliographic items, 3 to give more rapid processing to accelerate the availability of the information contained in the system, 4 to capture and deliver prescribed information from the total file and the variety of patterns of selection and arrangements [10]

The MEDLARS system is an extension of the *Index Medicus* that greatly expands the dissemination of information associated with medical literature MEDLARS broadens current awareness of subject areas by medical investigators and improves the quality of the reference system One of the greatest contributions to the use of this system is the depth in which one can do medical literature search The present day medical researcher is not interested in a broad category such as biochemistry Rather he is concerned primarily about small subsets of the field of biochemistry such as enzyme systems, amino acids, or DNA The MEDLARS system aspires to have a filing service within the next few years that will have an annual indexing rate of about a quarter of a million pieces of information The MEDLARS system could be

[9] Bourne, *op cit*, p 146

[10] Hillel Schiller, ' What is Medlars?," *Library Journal*, LXXXVIII, No 5 (March 1, 1963), pp 949–950

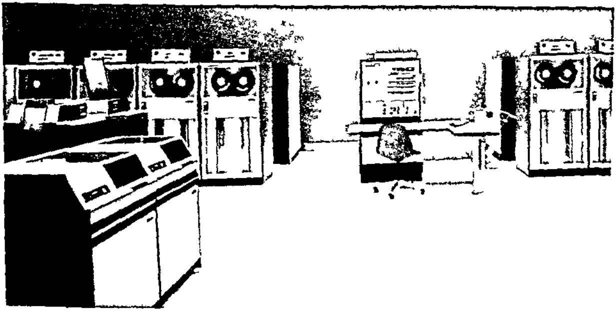


Figure 4.8. *IBM 360 total system.* (Courtesy IBM, White Plains, N.Y.)

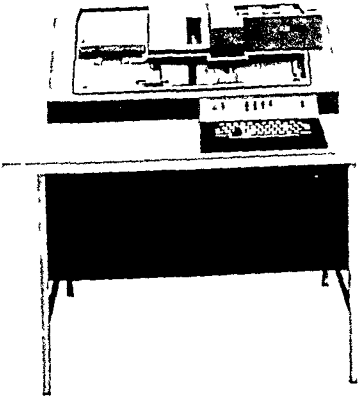


Figure 4.9. *IBM card punch* (Courtesy IBM, White Plains, N.Y.)

(a) input devices or devices associated with preparation of information from original sources (b) storage and operating devices, (c) output devices associa ted with retrieval of desired information

Figure 4 6 *NCR 315 total system* (Courtesy The National Cash Register Com pany Dayton Ohio)

Figure 4 7 *RCA 70 total system* (Courtesy R C A Camden N J)

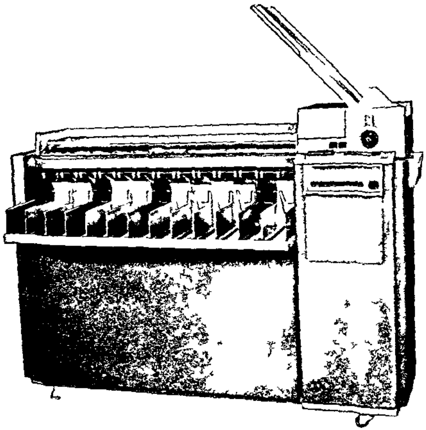


Figure 4 12 *IBM sorter* (Courtesy IBM, White Plains, N Y)

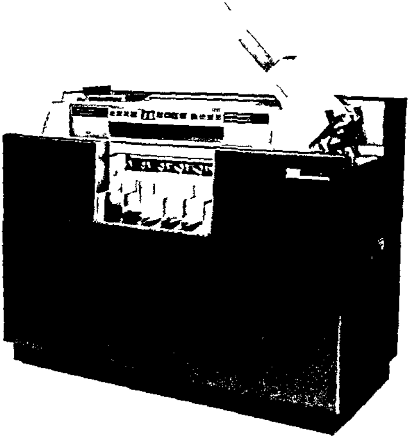


Figure 4 13 *IBM collator* (Courtesy IBM, White Plains, N Y)

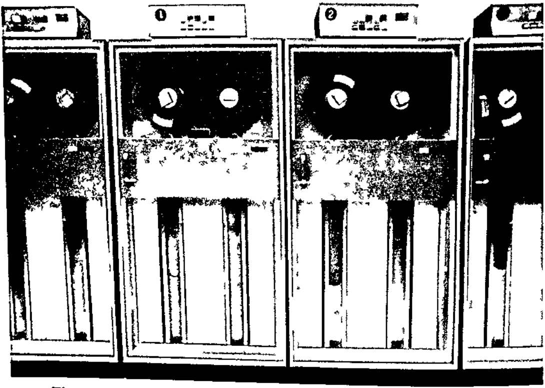


Figure 4.10. *IBM magnetic tape*. (Courtesy IBM, White Plains, N.Y.)

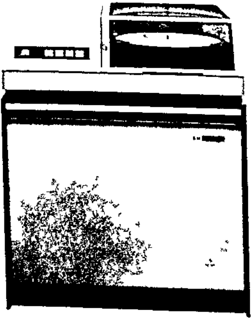


Figure 4.11 *Disk pack*. (Courtesy IBM, White Plains, N.Y.)

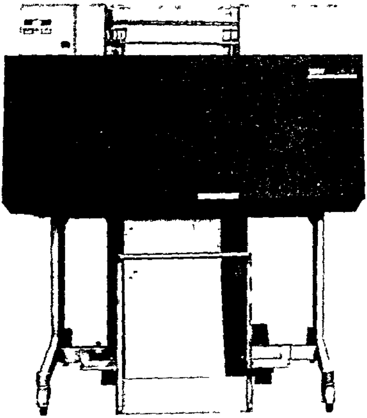


Figure 4.16. *IBM printer.* (Courtesy IBM, White Plains, N.Y.)

Figure 4.17. *IBM remote stations.* (Courtesy IBM White Plains, N.Y.)

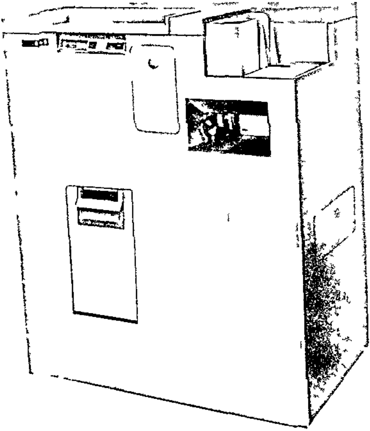


Figure 4.14. *IBM interpreter*. (Courtesy IBM, White Plains, N.Y.)

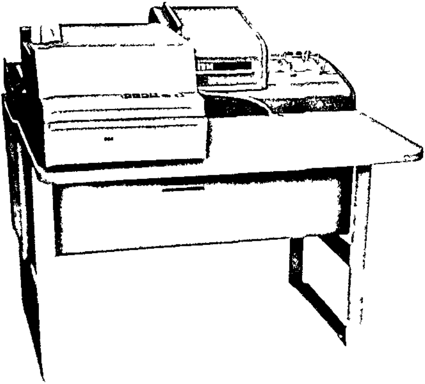


Figure 4.15. *IBM card tape converter*. (Courtesy IBM, White Plains, N.Y.)

from areas outside the field of education, there is growing evidence of the appropriateness of data-processing systems within the field of education

Data processing embodies all the complexities of an elaborate system composed of subsystems and auxiliary systems This complexity is the price paid for the speed and economy of a modern data system in education The very complexity of the system, however, contributes to the effectiveness of the system It allows for overall planning and control on the part of the administrator and enhances his decision-making capability

There are at least five factors that must be implemented in a successful data processing system The first factor is that of language A common technical language must be designed for the specific hardware in use The computer language referred to as a compiler allows the human operator to communicate with the hardware Unfortunately, as of this date there is very little sharing of language facilities among the various computer manufacturers The computer language (computer software) is an inherent part of the economics of the system A substantial portion of the expense of operating a computer center deals with the programming required for the hardware Therefore, the company that can offer a wide package of programs already written in the language of the computer has a considerable advantage in selling the basic hardware Research is now underway regarding the direct acceptance of oral input for the operation and control of computers The feasibility of this procedure has yet to be operationally demonstrated However, preliminary work with computer recognition of the spoken word offers encouragement for further research in this direction [17]

The second factor deals with information This is the basic input into the computer Adequate collection of data to serve to the processing unit is the key to the entire data processing operation The most sophisticated system is only as good as the information fed into it Unfortunately, a considerable amount of abuse has already been directed toward the computer There are those who feel that the solution to any data processing problem is to feed information into a computer Somehow this sophisticated system is supposed to transform inadequate information into reliable conclusions [18] The result is about as effective as a surgeon performing an operation with dirty hands and then tripling the amount of penicillin he administers to the patient

The third factor is that of machinery or central hardware The machinery itself can be thought of in terms of three subsystems input, processing, and

[17] Ralph C M Flynt, ' The Role of Data Processing " *Higher Education*, XX, No 3 (November, 1963), p 7

[18] *Ibid*

Other Storage Media

A popular visual storage device is the aperture card, which consists of a file card with microfilm mounted in a window of the card Numerous pages of typewritten text can be put on one piece of microfilm mounted in an IBM card Pictorial as well as typewritten information can be stored by this method [12]

A common archival storage device is the opaque microcard which is a stored positive picture with high resolution and long wearability The master film negative can be used to reproduce copies of the record as required One disadvantage of opaque microfilm is the method of viewing the information Once it is placed on cards, it is necessary to use reflected light rather than a transmitted light The opaque microcards, however, can be stored on individual frames or on film strips [13]

The FMA File Search System is a filing system involving thirty-five millimeter film The system utilized hundred foot rolls of film and has a capacity for storing up to thirty two thousand document pages per film The system is also designed to operate a search pattern for retrieval purposes and can handle up to six requests simultaneously [14]

The Benson Lehner Film Library Instantaneous Projection (FLIP) equipment can store nearly two thousand images at the rate of six hundred frames per second on a twelve-hundred foot roll of film The system operates as an automatic selector for viewing purposes [15]

The IBM Walnut system is a micro-image storage device for information systems It was developed by IBM in conjunction with the Federal Government The basic image file contains almost one million page-size images The retrieval system operates on a random access basis of five hundred aperture cards per hour of retrieval [16]

Data Processing Systems in Education

The early part of this chapter has been concerned with total information systems and how total information systems can be of use to the educational administrator Although resource material has been drawn rather heavily

[12] Bourne, *op cit*, p 195
[13] *Ibid*, p 198
[14] *Ibid*, p 202
[15] *Ibid*, p 203
[16] *Ibid*, p 213

however, modern society demands wider and wider acceptance of data processing equipment.[21]

The areas to which data processing have been applied to education include strictly local operations, administration, research, information retrieval, public relations, school business, personnel management, student and personnel accounting, and simulation of the total system. Within the strictly local operations are such things as personnel accounting, routine bookkeeping operations, check writing and related financial matters, student scheduling, the allocation of resources and details regarding guidance services. Under this local operations concept are those routine matters that traditionally have been handled by manual and clerical means.[22]

Administration includes such concepts as general administrative decision making, long range planning and immediate day by day decisions. For example, the administrator is assisted in his long range decisions regarding the number of buildings required, projected student enrollment, number of teachers required in various subject fields, number of preferable personnel needed, expenditures required for equipment and supplies, and such mundane things as transportation for students. Data processing equipment serves as a calculating tool for handling masses of data. It can be used to improve the adequacy of data needed for day by day operations of educational management and control.[23]

Data processing equipment is available for various types of research dealing with multi facets of the educational system. It can be used for analytical purposes where data (already on record) are analyzed for purposes of studying relationships, making projections, and furnishing profiles of the different subcategories of the school system. The greatest potential for research with data processing equipment, however, rests in the operational systems area whereby the administrator can continuously monitor his system and have immediate feedback regarding the various activities associated with the system. In this sense the decisions that he makes are based on latest information derived directly from the activities of the system. Normally the data frequently required for board meetings and dissemination to the public are made more readily available when stored within the data processing system.[24]

Information retrieval via data processing systems affords new concepts in terms of accuracy, time, and comprehensiveness. Use of data processing

[21] *Ibid*

[22] *Ibid*

[23] *Ibid*

[24] *Ibid*

output systems The input system can accept data in various forms One can feed data into the computer by means of punch cards, punch paper tape or magnetic tape Speed of the input increases according to the sequence of the above referenced modes of input (The central processing unit is now available in hardware that operates in nanoseconds A mere dozen years ago computing equipment was sold on the basis of its speed in milliseconds Shortly thereafter calculating speeds advanced to microseconds The latest hardware advertises in nanoseconds) The third subsystem of the hardware involves output comparable to the input system The output system can take the form of punch cards, paper tape, magnetic tape, or high speed printer Also available are input and output devices that can be operated from remote stations For example, a person in California can dial into computing facilities anyplace in the Eastern part of the country that has appropriate reception Data-processing equipment has literally reached the stage where one can stop off at a motel in the evening, request a data phone hook-up and use a computer at some central location any place in the country [19]

The fourth factor is that of the human operator The impact of computer technology upon the present-day work force has been substantial One leading industrialist indicates that the production of the computer has been the most significant breakthrough in the history of scientific technology This is especially relevant to the field of education—not only to professional education as an absorber of this technology but also to planning programs that must begin quite early in the student's career In many places secondary schools now operate their own computer for the sole purpose of training the students in computer technology The need for programmers, operators, and systems analysts continues to grow at an exponential rate and will continue to accelerate over the foreseeable future The real impact of the computer as a part of the total system has yet to be exploited in the field of education or by society in general [20]

The fifth factor of concern is that of economics A computer system is very expensive in terms of the original investment in hardware and of the necessary staff that goes into the maintenance of an adequate system The justification for the large expenditures rests primarily in the increased speed and the greater number of activities that can be conducted with a computerized system Many studies have been conducted attesting to the feasibility of a computer system strictly on the basis of economics Regardless of economics,

[19] *Ibid*
[20] *Ibid*

socioeconomic data, population trends, and other pertinent data, educational planners can cycle a program and generate predictions about future educational needs The primary contribution of data processing equipment for simulation purposes allows the simulator to study the interrelatedness of the total system without fear of making errors The time factor for several years of study can be compressed into a few short weeks and trainees can experience the excitement of the real situation before being placed within the real situation [29]

The demands today for automated data systems are evidence of the growing demand for information This demand for information is accentuated by the rapidly increasing population growth in addition to the exponential increase in information available The volume of repetitious tasks has become difficult to handle because of the time that is consumed in doing them Inevitably errors are introduced when manual or clerical computations are done Therefore, manual methods of accumulating educational data are simply no longer adequate to handle the volume of work to be done Automating the required administrative details means a saving of time and money and more importantly the introduction of a new standard of accuracy [30]

There are many types of data-processing systems available These range from manual systems to semiautomated bookkeeping machines The computer allows modifications of programs that result in completely automated systems At the present time, because of the almost limitless storage capacity and extremely high speed of computers, it is possible to handle the increasing technical information and to gain more from that information [31]

Equipment is now available to read routine documents directly from printed materials at tremendously high rates of speed Systems are in use that automatically read, store, and retrieve original documents and then print-out the contents With the increasing sophistication of mathematical models for analyzing data, more effective interpretation of available data is taking place

Applications of data processing equipment to specific educational projects is stated in a report by Rolens "A school district recently registered 3,000 students on a large computer costing $200 00 an hour, but the computer needed only about 6 6 minutes at a cost of about $24 "[32]

[28] *Ibid*, pp 269–270
[29] *Ibid*, pp 274–275
[30] Richard A Kaimann and Brother Leo V Ryan, C S V, "Efficient School Management Demands Data Processing" *Catholic School Journal*, LXIV, No 7 (September, 1964), pp 91–92
[31] *Ibid*, p 92
[32] Robert E Rolens, "Data Processing for Building Schedules and Student Registration," *Journal of Secondary Education*, XXXIX, No 2 (February, 1964), p 68

equipment for information retrieval greatly reduces the operating costs and allows a step up in the speed of retrieval New coding schemes provide a high selectivity factor that eliminates unnecessary work By the use of such systems as key-word indexing, it is possible to search an entire file of literally millions of pieces of information and select the appropriate document or student record One could search thousands of records in a large school system in a matter of seconds to pick out those students who have the unique characteristics sought under the key word indexing system As an illustration one might want to survey all twelfth graders who are male and indicate an interest in mathematics The three key words deal with the grade, sex, and subject Only those subjects possessing all three characteristics will be utilized, all other files will be ignored [25]

The primary contribution of data processing equipment to public relations centers on the ready availability of information as it is stored in the data-processing equipment There are continuous demands from various segments of the community such as PTA's, pressure groups, interested citizens groups, and bond promotions that require data about the school system Most school systems do indeed have such data, but the time required in selecting them by manual means precludes their usefulness By the time they are retrieved for public relations purposes, the issue will have been long settled Only by quick recall via some type of automated system are such data maximally useful [26]

Applications to school business and staff personnel management include such common areas as payroll, receipts, supply acquisitions, accounts of personnel, master files, detailed information regarding specific class loads, teacher assignments, size of classes, inventory, and files on personnel and equipment [27]

Student accounting is quite similar to staff accounting in terms of the multitude of records required for each student There is a growing realization that data processing equipment can automate many of the mechanical functions associated with the maintenance of student records There are schools now using computing equipment for such things as grading, making report cards, class scheduling, student attendance records, summary reports, individual testing, and guidance matters [28]

One final application of data processing equipment that should be mentioned is the use of simulation of the educational system By simulating educational systems for a given region and utilizing such information as

[25] *Ibid*, pp 8-9
[26] *Ibid*, p 9
[27] James Whitlock, "Automated Data Processing in Education," *The High School Journal* XLVII, No 4 (January, 1965), pp 268–269

enrollment with only one additional room One of the major contributions of going to a computerized system was that it saved teachers time from becoming involved in small jobs, grade reporting, and other minor details[35]

Sinks has also pointed out that "this memory factor in the machine is an interesting possibility for replacing the cumbersome cumulative folder system in the schools" With the increasing problems attendant upon both storage and retrieval, it becomes apparent that some type of a reduced storage system must be substituted for the more cumbersome paper records At present a computer storage system seems to be the only solution to that particular problem[36]

Howe reports that the Department of Education's Research and Development Center in Data Processing is an integral part of the Bureau of Pupil Personnel Services' long-term view of automation's prospects for a more humanized education process He points out that the bureau's basic research continues to expand on the outline developed in 1959 by the state advisory committee on integrated data processing and to build on the firm foundation furnished by the three-year punch-card pilot project at Richmond, Indiana Considerable study has gone into this project and nine statewide task-oriented committees of educators, data processors, and laymen have determined new possibilities for minimizing clerical work of teachers, counselors, and administrators Although many of the current educational projects are designed primarily for the elimination of routine tasks, the real contribution of the data-processing system in education should rest in more sophisticated methods of analyzing available information Consequently, it is in the realm of administrative decision making and planning and control that data processing systems will make a major contribution

In the project reported by Howe, accomplishments to date include tentative definitions of (1) items needed for records on students and curriculum, (2) common course-coding system applicable to all areas and levels and (3) data for transcripts and transcript formats It is reported that such activity converts these data into usable reports prepared for specific members in a form that facilitates action or suggests needed areas of study[37]

Gates has reported on the use of data processing equipment more specifically related to information science He reports about objectives in the state of Florida as being "   to help the student keep his individuality, the Florida

[35] *Ibid*, pp 118–119
[36] *Ibid*, p 120
[37] Robert L Howe, "New Vistas in Data Processing," *California Education*, I, No 3 (September, 1963), p 12

Considerable detailed information must be available for the registration of students information about teachers, facilities, student requests, frequency of course selection, conflicts, etc In the project reported by Rolens, a counselor did not have to write the name of the student or the name and number of the course A total of twelve marks was all that was required for student registration, whereas, most scheduling operations required at least two passes of all student cards in order to complete registration From 85 to 90 per cent of the students ordinarily could be registered without conflicts The requests of those students with conflicts were printed-out along with their names, and the conflicts could be resolved by hand [33]

As reported by Sinks, Nichols Junior High School in Evanston, Illinois, was confronted with the problem of increasing enrollment and the demand for more science and language courses The first reaction was a natural one —to increase the staff As consideration was given to additional staff, something also had to be done about rooms for those classes The immediate goal was to find a way to accept the largest possible number of students within the building and at the same time to retain the curriculum as free of restrictions as possible This hard look at the primary goal involved scrutinizing schedules in terms of time and space It was found that some of the teachers had rooms reserved for their exclusive use There were also space and time requirements for nonteaching assignments of professional teachers [34]

A solution to the Nichols Junior High problem was found by obtaining a multiple-access computer that allowed maximum flexibility in performing a multitude of tasks simultaneously The entire staff participated in discussions regarding various changes It would have been impossible for any one person or group of persons to handle the many facets of this particular problem However, the computer could handle such a problem with accuracy and speed As a result of utilization of equipment at Nichols Junior High, it was found that data furnished by the multiple-access computer enabled better decisions about future plans in so far as scheduling was concerned, such as dropping activities, adding others, or maintaining the original schedule The punch card system offered over seventy-five activities to students and gave 96 per cent of them first or second choices on schedules In addition, considerable flexibility was furnished in terms of actual classroom time periods The multiple-access computer gave data to show accommodation of a 20 per cent increase in

[33] *Ibid*, pp 69–70.

[34] Thomas A Sinks, "Data Processing in the Schools," *The Clearing House*, XXXIX, No 2 (October, 1964), p 118

that require manual clerical workers to get out routine reports The major change in direction would seem to be toward a more sophisticated application of data-processing equipment Administrative staff would utilize the equipment as a part of a total information system that would allow continuous monitoring of various activities of the system Another contribution seems to be indicated in the fact that the tremendous amount of information in storage in the central office of a typical school system would be made available within a matter of minutes upon demand Such ready accessibility of information should be a tremendous asset to the administrator pressed with constant decisions both of an immediate and a long-range nature

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State Department of Education has instigated the use of electronic data processing thru-out [*sic*] its 67 counties Florida, according to Gates, is the only state that collects, on a statewide basis, data on pupils, teachers, instructional facilities, teaching materials, and overall costs Although such data have thus far been used primarily to schedule courses, keep track of grades, and to help in obtaining financial support, their use doesn't stop there"[38] The use of the Florida Data Processing System allows quick access to information regarding students, teachers, and courses, and it also helps for the compilation of periodical reports

In other accounting and financial matters, EDP can perform record keeping functions for a school business manager and keep personnel files on teaching and nonteaching staff As fiscal management becomes more sophisticated, there is a need for a complete integration of financial reports regarding a total budget, various purchases, accounts, and inventory problems EDP allows for more uniform accounting procedures and better business management and control [39]

Kaimann and Ryan have reported on the instructional program related to data processing In terms of vocational training, terminal students have an opportunity to qualify for jobs in the data processing field Such jobs include key punching, panel wiring, machine operation, and some elementary business programming For the college bound student who has an interest in science or mathematics, opportunities exist in engineering and programming fields There is a tremendous demand at the present time for both hardware and software improvements in the computer industry These positions are of concern to educators That concern is being reflected in the introduction of data-processing courses into the secondary school [40]

Summary

The various applications of data processing-equipment to educational systems referred to in the preceding pages indicate only the beginning awareness of possible applications of modern electronic equipment to the operation of schools To date the primary applications have been to the routine tasks

[38] Bob Gates (reviewed by F J C. Mundt) "Information Science A New Day in Education" *Audiovisual Instruction*, IX, No 7 (September, 1964), pp 409–410

[39] Richard Kaimann and Brother Leo V Ryan, C.S V, "Efficient School Management Demands Data Processing," *Catholic School Journal*, LXV, No 1 (January, 1965), pp 56–57

[40] *Ibid*, LXIV, No 9 (November, 1964) p 81

CHAPTER 5

Information System Design

Introduction

Chapter 4 presented the general philosophy of an integrated information system for educational management Emphasis was placed upon the contribution of a unified information system to management decision making

This chapter furnishes a detailed guide for the design of a comprehensive, unified information system The logical layout presented in flow-chart form is given for four areas personnnel, inventory, students, and fiscal management Modification requirements are assumed for each installation because each system has unique requirements

Personnel Record System

The flow chart in Figure 5 1 depicts the flow of personnel documents The source documents reflect new information, payroll changes, and permanent record changes Where possible these documents should be mark-sense type The mark-sense documents are sent to mark-sense punch, where new-information and record-changes cards are punched The cards go to the computer where the payroll and record changes are processed, the payroll and personnel master tape is updated, and the cards are filed Reports are printed from the

Schiller, Hillel "What is Medlars?," *Library Journal*, LXXXVIII (March 1, 1963)

Sinks, Thomas A "Data Processing in the Schools," *The Clearing House*, XXXIX (October, 1964)

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ment, noninstructional personnel records are enhanced by the automated record system For example, the noninstructional personnel records are retrievable by skill Therefore, if there is a need for a number of air-conditioning repair experts, those persons can be identified quickly from the personnel master tape

Inventory

The automated inventory control system that follows assumes an independent division for inventory control The system design represents three aspects of the inventory control problem new inventory items, issuing items from inventory, and inventory maintenance

Figure 5 2 depicts the document flow for new inventory items An inventory control card is initiated at purchasing A mark-sense inventory report is also initiated at purchasing The inventory control card is sent to the inventory division, and the mark sense inventory report is sent to the school or department Inventory-mark-sense cards are punched when the inventory item arrives at the school or department The inventory control card that is initiated by purchasing carries the information that an inventory item has been delivered The school or department also initiates a card verifying that the item has been delivered These two cards are matched within the computer If the cards match, the item has been delivered The matched cards are then used to update the inventory records If the cards do not match, a list of discrepancies is printed, and the unmatched cards are returned to the original inventory division

Figure 5 3 presents information regarding issuing items from inventory The source document is a requisition form preferably in mark-sense format Mark-sense cards are fed into the computer and the inventory record is updated The shipping cards are cut, appropriate sorts are made, and the cards are sent into the computer for warehouse listing and issue listing

Figure 5 4 charts the flow for inventory maintenance

The inventory record is monitored by the computer The computer prints an inventory document The printed document is used for manual inventory check The revised inventory document is returned to inventory after the manual check, and cards are punched These cards are used to update past inventory records A new inventory list is printed

As part of the inventory-control procedure an inventory-control model is used that permits machine monitoring of the system The model furnishes

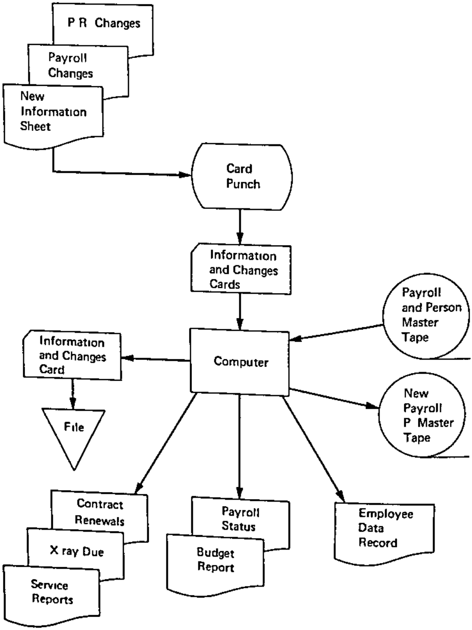


Figure 5 1. *Personnel system*

updated master tape Since the master tape contains the comprehensive personnel data file, it can also be used for retrieval purposes when specific personnel information is desired

Personnel information is needed for two purposes payroll and assignment One master tape can handle both functions Management should make some effort regarding efficient usage of the personnel system In terms of assign-

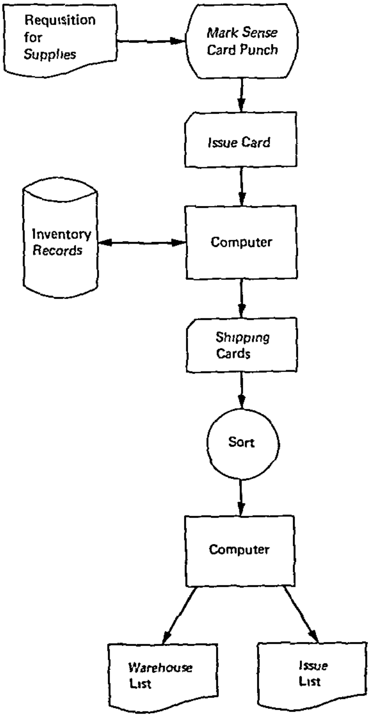


Figure 5.3. *Issuing Items—Inventory.*

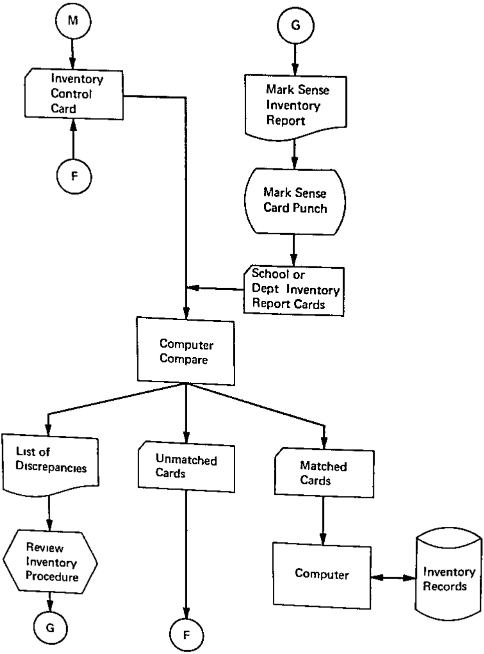


Figure 5.2. *New inventory items*

the inventory division with optimal times between orders and optimal order sizes An illustration of an inventory model follows

Assume a simple inventory problem that involves a relatively large amount of school-supply items There are two cost factors: cost of holding an item in inventory C_i per unit of time and administrative costs for purchasing and handling C_s per order. The essential factors are the total amount A

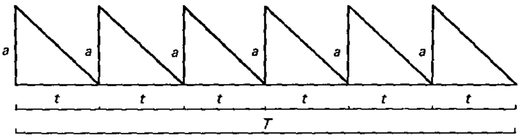


Figure 5.5. *Inventory control.*

needed during some time period T and an amount a received per order that will meet requirements during time t. No shortages are permitted. The objective is to optimize a and t (Figure 5.5.)

The following definitions are given for Figure 5.5.

$T =$ total time period for which supplies are needed.
$A =$ total number of items needed during the total time period T.
$t =$ time period for which a items will last or time between orders.
$a =$ number of items acquired per order.
$C_i =$ inventory cost per item per time unit.
$C_s =$ administrative cost per order.
$A/a =$ number of orders during time T.

$$\frac{T}{A/a} = \frac{Ta}{A} = t.$$

$a/2 =$ average inventory during t.
$(a/2)C_i t =$ inventory costs during t.
$(a/2)C_i t + C_s =$ total cost during t.

$$\left[\left(\frac{a}{2}\right)C_i t = C_s\right]\frac{A}{a} = \text{total cost during } T = C_T.$$

Substituting for t,

$$C_T = \left[\left(\frac{a}{2}\right)C_i T\left(\frac{a}{A}\right) + C_s\right]\frac{A}{a}$$

$$C_T = \frac{C_i Ta}{2} + \frac{C_s A}{a}.$$

The graph for C_T is given in Figure 5.6 along with the graphs (dotted lines) of each of the constituent parts, that is,

$$\frac{C_i Ta}{2} \quad \text{and} \quad \frac{C_s A}{a}.$$

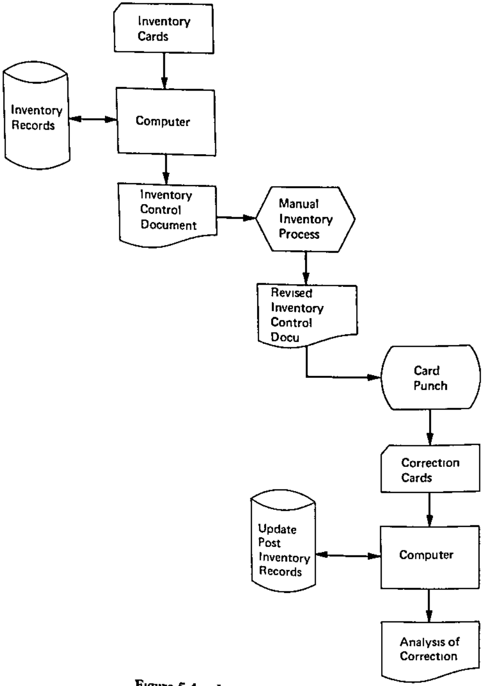


Figure 5 4. *Inventory maintenance*

each time The amount a_0 will last for a period of time T_0

$$t_o = \sqrt{\frac{2TC_s}{AC_i}}$$

for a total cost of

$$C_{T_0} = \sqrt{2ATC_i C_s}$$

To complete the example, the following numerical information is given Let

$$\begin{aligned} T &= 6 \text{ months} \\ A &= 100{,}000 \text{ items} \\ C_i &= \$00\ 01 \\ C_s &= \$50\ 00 \end{aligned}$$

then

$$a_o = \sqrt{\frac{(2)\ (100{,}000)\ (50)}{(6)\ (\ 01)}} \simeq 12{,}909 \text{ items}$$

$$t_o = \sqrt{\frac{(2)\ (6)\ (50)}{(100{,}000)\ (\ 01)}} \simeq 776 \text{ months}$$

$$C_{T_0} = (2)\ (100{,}000)\ (6)\ (\ 01)\ (50) - \$7{,}760$$

Each order should be for 12,909 items An order should be placed every 776 months or approximately every twenty three days The total cost for the six-month period would be $7,760

Student Records

At the time of original registration the student fills out a student personnel information form This document proceeds through the system as in Figure 5 7

Student-information cards are punched from the source document These cards are fed into the computer Reports are furnished for the permanent record, health, and welfare Noncourse activities and files are updated through this procedure A list of personal information with card columns assigned is given in Table 5 1

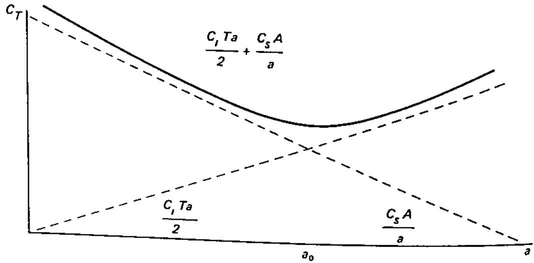


Figure 5.6. *Graph for C_T.*

One can find a_0 by taking the derivative of the function

$$C_T = \frac{C_i T a}{2} + \frac{C_s A}{a}$$

in respect to a and setting the derivative equal to zero

$$\frac{d(C_T)}{da} = 0$$

that minimum value will occur at a_0

The following values for a_0, t_0 and C_{T_0} are derived from the minimum value of the function C_T. Solve first for a_0 then substitute for t_0 and C_{T_0} values

$$a_0 = \sqrt{\frac{2AC_s}{TC_i}}$$

$$t_0 = \sqrt{\frac{2TC_s}{AC_i}}$$

$$C_{T_0} = \sqrt{2ATC_i C_s}$$

For minimal total cost C_{T_0} one should order the amount of items

$$a_0 = \sqrt{\frac{2AC_s}{TC_i}}$$

Table 5-1 Personal Data*

Columns	Card description and layout
1	Card number 1—enter 1
2–10	Student number
11	Check digit
12–25	Student last name—use legal name with no space between compound names
26–28	Appendages—Jr , Sr , III, etc
29–38	Student first name—use legal name with no space between com pound names
39	Student middle initial
40–61	Student address—Street Five spaces for house number Fourteen spaces for street name Three spaces for suffix St , Ave , Bvd , Way, etc
62–74	City—use only space provided
75–77	State—use postal abbreviations
78–79	Present grade
80	Change
1	Card number 2—enter 2
2–11	Student number—same as appears on card number 1
12–16	Zip code—student address
17	Sex M or F
18	Race Code 1 White 2 Negro 3 American Indian 4 Oriental 5 Other
19–24	Date of birth 2 digits for month 2 digits for day 2 digits for year

* Modeled after the Florida Association of Educational Data Systems

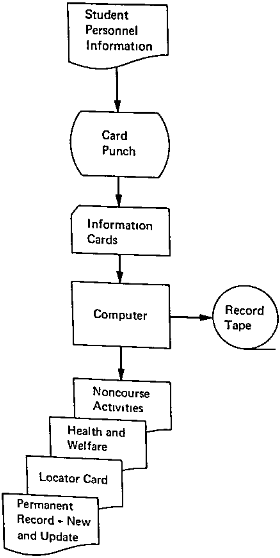


Figure 5.7. *Student personnel.*

Table 5-1 Personal Data*

Columns	Card description and layout
1	Card number 1—enter 1
2–10	Student number
11	Check digit
12–25	Student last name—use legal name with no space between compound names
26–28	Appendages—Jr , Sr , III, etc
29–38	Student first name—use legal name with no space between compound names
39	Student middle initial
40–61	Student address—Street Five spaces for house number Fourteen spaces for street name Three spaces for suffix St , Ave , Bvd , Way, etc
62–74	City—use only space provided
75–77	State—use postal abbreviations
78–79	Present grade
80	Change
1	Card number 2—enter 2
2–11	Student number—same as appears on card number 1
12–16	Zip code—student address
17	Sex M or F
18	Race Code 1 White 2 Negro 3 American Indian 4 Oriental 5 Other
19–24	Date of birth 2 digits for month 2 digits for day 2 digits for year

* Modeled after the Florida Association of Educational Data Systems

Columns	Card description and layout
25	Verification of birth Code 1 Birth Certificate 2 Baptismal record 3 Insurance policy 4 Bible record 5 Passport 6 Transcript 7 Sworn affadavit 8 Not verified
26–29	Place of birth—state Use U S Post Office abbreviation for the state If foreign born, put F in the first space
30	Marital status of student Code 1 Single 2 Married 3 Separated from spouse 4 Divorced 5 Widowed
31	Citizen for the USA 1 for yes 2 for no
32	State residence 1 for yes 2 for no
33	Date of original entry 2 digits—month 2 digits—day 2 digits—year
39–44	Date of most recent entry 2 digits—month 2 digits—day 2 digits—year
45	Type of entry Code † 1 E-1 2 E-2 3 R-1

† For definitions see State Attendance Register

Columns	Card description and layout
	4 R-2 5 R-3 6 R-4
46–51	Date of most recent withdrawal 2 digits for month 2 digits for day 2 digits for year
52	Type of withdrawal Code 1 W1 2 W2 3 W3 4 W4 5 W5 6 W6 7 W7
53–58	School last attended If the last school attended is the same as the one being entered, or was in state, use the first two digits for the county number and the last four for the school number
59	Transcript received 0 for yes 1 for no
60	Out of state tuition paid Code T Tuition D Manifestation of domicile was used to avoid payment H Tuition voided—hardship E Exemption—other reasons N Not applicable
61	Class instructional material fee paid 0 for yes 1 for no
62–71	Telephone number Area code Telephone number
72	Transported 0—yes 1—no
73–75	Bus number

Columns	Card description and layout
76–78	Route number
79	Transcript mailed
80	Change
1	Card number 3—enter 3
2–10	Student number—same as appears on card 1
11	Check digit
12–25	Last name—male head of house Use legal name with no space between compound name
26–35	First name—male head of house
36	Middle initial
37–58	Address of male head of house—repeat address even if same as student address 5 spaces—house number 14 spaces—street number 3 spaces—street designation St , Ave , Bvd , Way, etc
59	Relationship of male head of house to student Code 1 Father 2 Stepfather 3 Other relative 4 Legal guardian 5 Foster parent 6 Self 7 None 8 No information available
60	Occupation Code 1 Professional 2. Paraprofessional 3 Skilled 4 Unskilled 5 Retired
61–73	Name of city—repeat town even if same as student
74–76	Name of state—repeat if necessary
77–79	Blank spaces
80	Change
1	Card number 4—enter 4
2–10	Student number
11	Check number

Columns	Card description and layout
12–21	Telephone number—guardian
22–35	Last name—female—head of house
36–45	Maiden name—female—head of house
46–67	Address of female head of house—complete even if repeated 5 spaces—house number 14 spaces—street name 3 spaces—street designation St , Ave , Bvd , Way, etc
68	Relationship—female head of house Code. 1 Mother 2 Stepmother 3 Other relative 4 Legal guardian 5 Foster parent 6 Self 7 None 8 No information available
69	Occupation Code. 1 Professional 2 Paraprofessional 3 Skilled 4 Unskilled 5 Retired 6 Housewife
70–79	Telephone number of female head of house 3 spaces—area code 7 spaces—telephone number
80	Change
1	Card number 5—enter 5
2–10	Student number
11	Check digit
12–24	City
25–27	State
28–37	Emergency telephone
	PHYSICAL IMPAIRMENT CODE: 1 FOR YES; 2 FOR NO
38	Visual
39	Hearing
40	Speech

Columns	Card description and layout
41	Heart
42	Epilepsy
43	Motor
44	Allergies
45	Other
46–49	Last physical examination—month and year
50–63	Family physician—last name only
64	First initial
65	Middle initial
66–75	Physician's telephone number
76–79	Blank
80	Change
	NONCOURSE ACTIVITIES
1	Card Number 6—enter 6
2–10	Student number
11	Check digit
12–14	Noncourse activity
15	Level of participation Code 1 President, captain, editor, or group leader 2 Other elected officer, committee chairman, a letterman 3 A participating member not holding a previously rated position
16–17	Year of participation
18–20	Identical space allotment for additional noncourse activities
21–23	Additional noncourse activity spaces
24–29	Additional noncourse activity spaces
30–35	
36–41	
42–47	
48–53	
54–59	
60–65	
66–71	
72–77	
78–79	
80	Blank Change

Figures 5 8 and 5 9 furnish a detailed breakdown of the process of registration The student meets with his counselor for course selection The course selections are made on mark-sense sheets Cards are mark-sense punched The course selection cards are sorted and fed into the computer along with drop and add cards A preliminary course selection list is printed Summary cards are cut by subjects The subject record is updated Subject cards are again processed and a listing is given of enrollment by subject

The selection cards are fed into the computer to produce a master tape, schedule by subject and schedule by period Selection cards are processed in the computer to update the subject record and to cut class cards Class cards are processed to produce the student schedule and assign students by classrooms

Before class lists are printed, drop and add cards are mark-sense punched and read into the computer Class lists are then printed and class cards filed

Figure 5 10 illustrates the logic of automated attendance reporting Twenty-day attendance cards are mark-sense punched after being initiated with the classrooms New registration and/or withdrawal cards are read into the computer with the twenty-day attendance cards After a validity-balance check is made, routine reports are printed and an attendance-summary card is cut The attendance-summary card is read into the computer, and new summary and balance cards are cut The new cards are then read into the computer, and routine reports are printed

Figure 5 11 represents a flow chart of student testing procedure The test answer sheets are mark sensitive and are read by the mark-sense processor, and the tests are scored The raw-score answer card is read into the computer and test results are stored on tape The test results are available for permanent records, administrative summaries, counselors, and required reports

Figure 5 12 charts the procedure for grade reporting The attendance card and mark-sense punched-grade report card are read into the computer with the guardians' name and address card The grade report tape is updated Grade reports are machine prepared and required listings are made

Figure 5 13 summarizes the permanent record preparation The pupil registration form is mark-sense punched The card is read into the computer, and the students permanent record tape is created The test results are added to the permanent record tape as are the grade reports Any printout is available from the updated permanent record

Figure 5 14, which depicts budget preparation, is not necessarily a part of the automated fiscal management procedure However, it is included here because proper scheduling of the administrative aspects of fiscal management

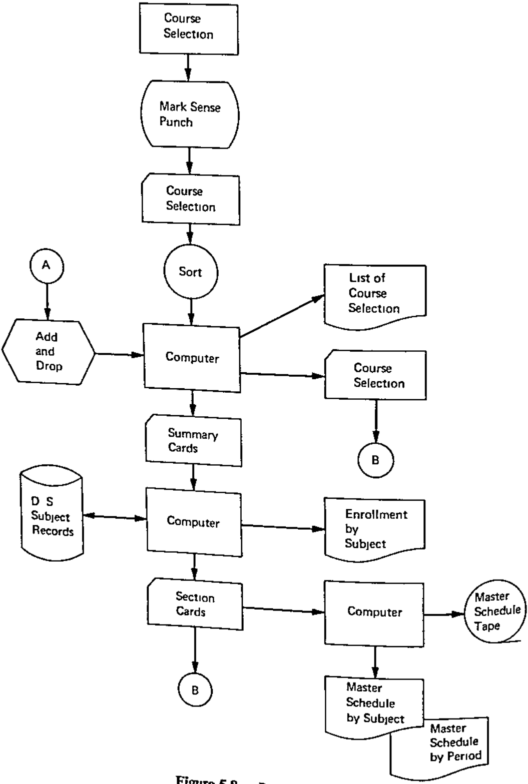


Figure 5.8. *Registration.*

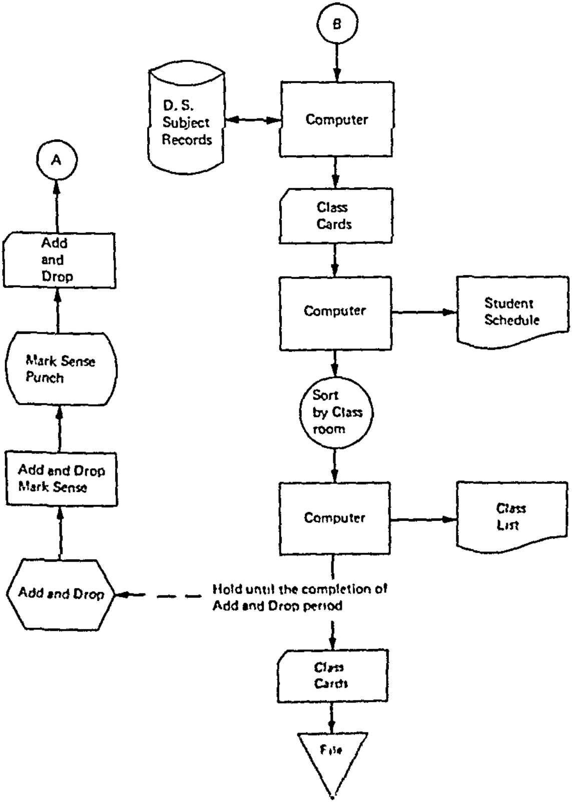


Figure 5.9. *Registration*

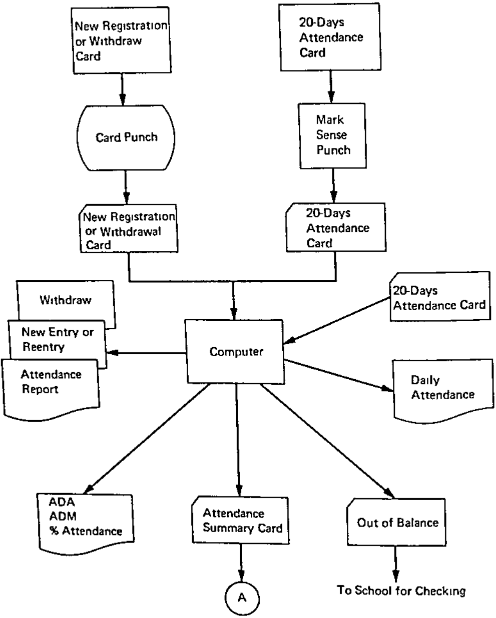


Figure 5.10. *Attendance*

is essential if the automated system is to function properly Budget preparation is a continuous process Although no time estimates are given in the schedule in Figure 5 14, realistic estimates should be made for each step in the budget-making process Sufficient log time should be made available to assure possible alterations in the budget From Figure 5 14 one notes that an estimate of the school population for the next year is one of the first steps Also an early estimate of the fiscal resources is made A budget request form is sent to schools and department heads When fiscal needs are received from the

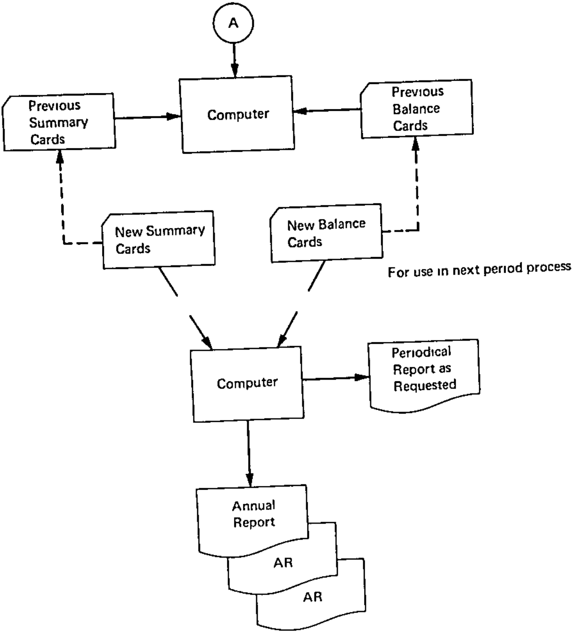


Figure 5.11. *Attendance*

schools and department heads, a computer simulation can be run to match estimated resources with requested funds

After matching, a recommended salary schedule is made followed by the preparation of the preliminary budget A review of the preliminary budget is made by school officials A final budget is prepared and approved The final approved budget is stored for future monitoring purposes

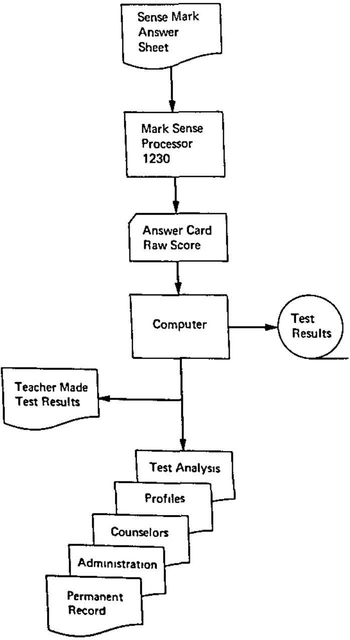


Figure 5.12. *Testing*

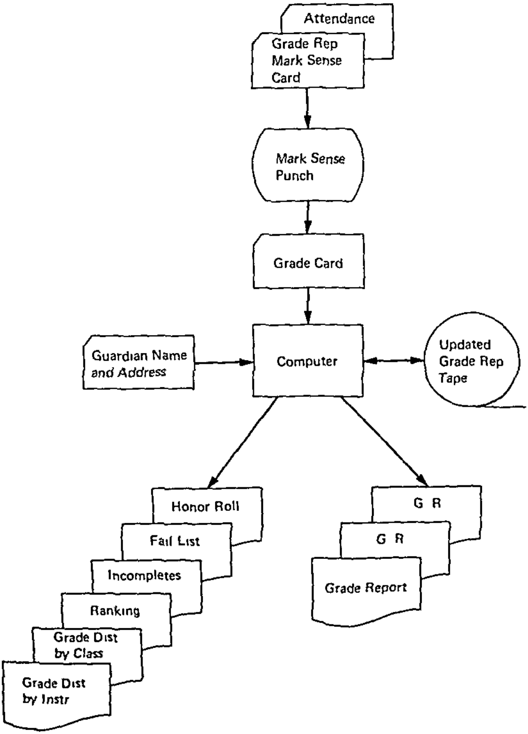


Figure 5.13. *Grade reporting*

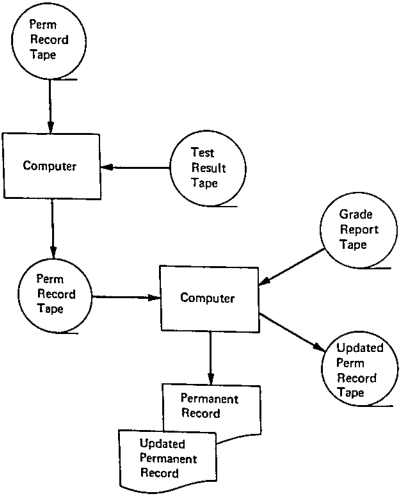


Figure 5.14. *Permanent record.*

Figure 5.15 outlines the steps in the payroll procedure. Data are entered from the master payroll tape. A payroll prelist is printed. Current payroll information is mark-sense punched. The current payroll information is read into the computer. A new updated payroll master tape is created and budget items are appropriately adjusted. Checks are written, and necessary reports are printed.

Figure 5.16 charts the purchase requisition document flow. The source document is a purchase requisition form. A bidding decision is made followed by determination of the type of purchase order required. The purchase orders with necessary copies are created and encumbrance cards are punched. The encumbrance cards are read into the computer and the necessary budget adjustments are made

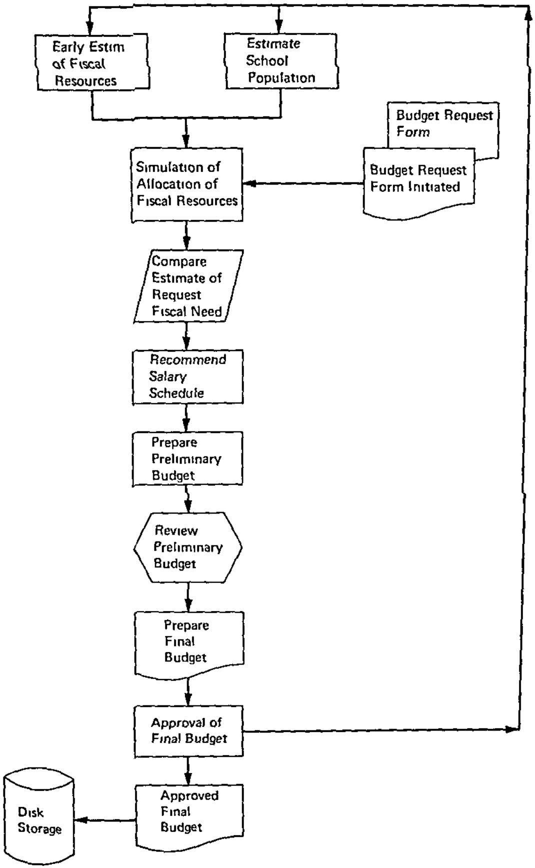


Figure 5.15. *Budget preparation.*

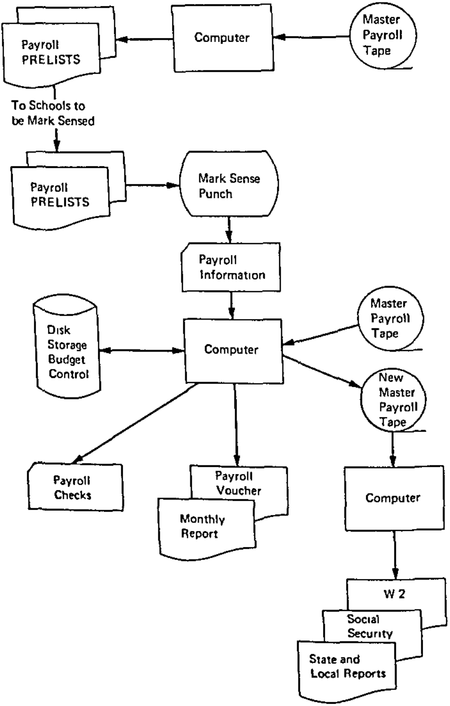


Figure 5.16. *Payroll*

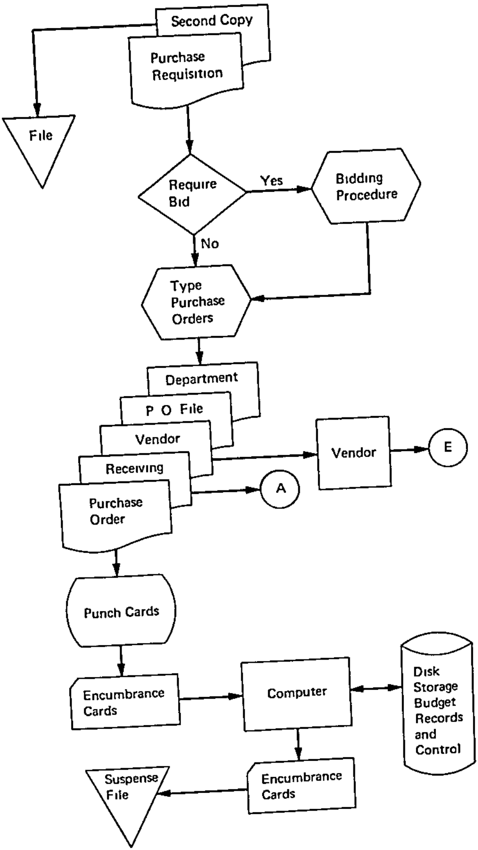


Figure 5.17. *Purchase requisition.*

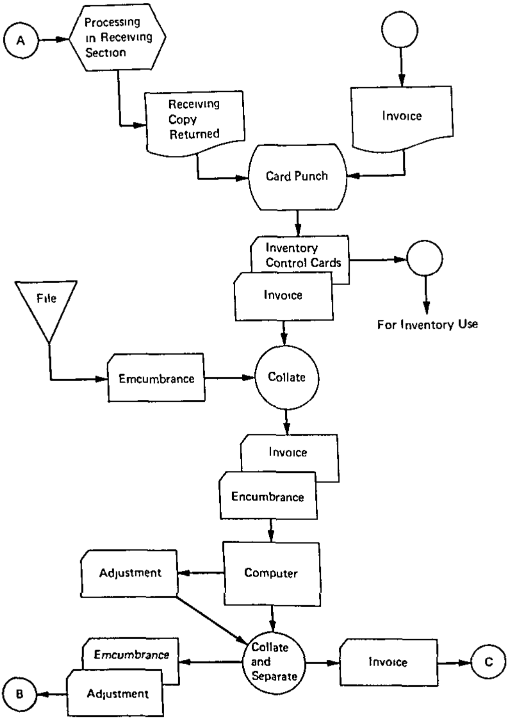


Figure 5.18. *Receiving.*

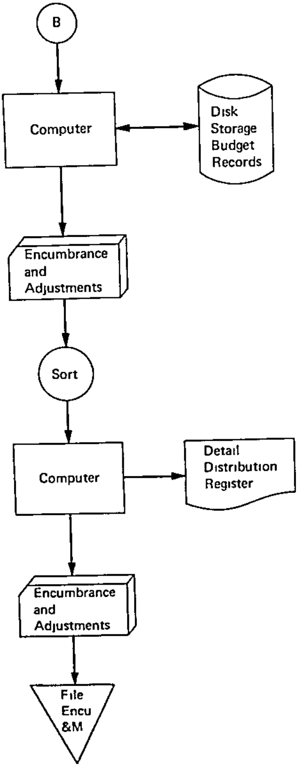


Figure 5.19. *Encumbrance and adjustments.*

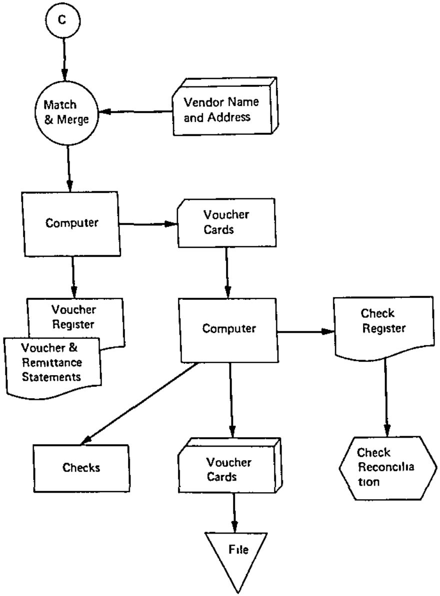


Figure 5.20. *Invoice.*

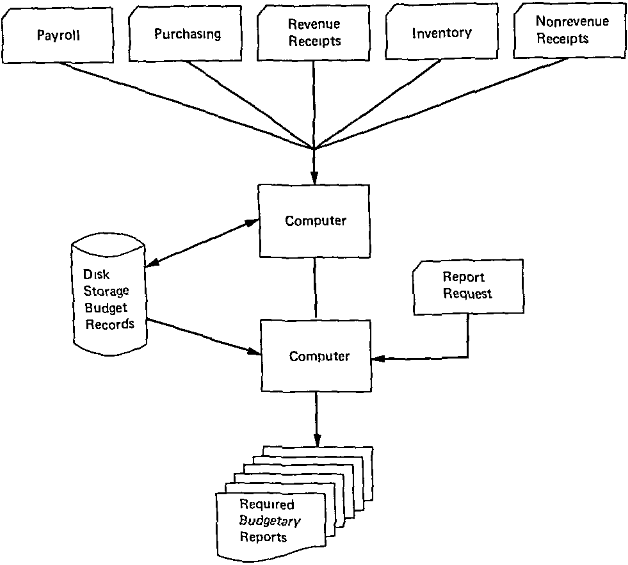
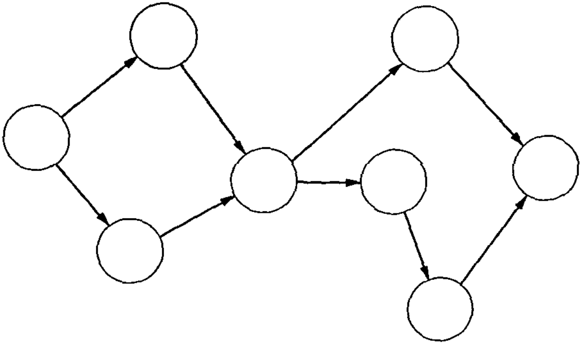


Figure 5.21. *Budgetary accounting*

PART **THREE**

SYSTEMS APPLICATIONS



CHAPTER 6

Planning and Control

Brief History of Control Systems

Many administrative concepts that are concerned with control have their roots in the physical and engineering sciences. Indeed, the earliest work in this area predates systematic investigations of the sciences. For example, it is possible to trace the present-day information systems and control of complex plant operations via computer back over three hundred years.[1]

In 1642, Pascal developed an operational digital computer. Although his computer was designed with a capability for only adding and subtracting, the primary motivation was to free man of the tedious tasks associated with lengthy calculations. Therefore, Pascal's computer represented a major step in the direction of turning over to automated equipment tasks that could be handled without direct human intervention. A consistent and rapid development combining hardware and methodology dealing with systematic planning and control was beginning.

Only a short time after Pascal developed his computer Leibnitz made an improvement. In 1673, Leibnitz developed a computer that was capable of multiplication and division as well as addition and subtraction. The pressures to develop this type of equipment were no doubt associated with the growing

[1] R. H. MacMillan, *Automation: Friend or Foe?* New York: Cambridge University Press, 1956.

scientific orientation plus a growing need for mathematical manipulation Although Pascal and Leibnitz were not interested in administrative problems, they were interested in concepts that were to play a major role in administrative planning Most of the major milestones in the development of hardware and methodology that contributed to administrative planning and control were developed by persons who had no interest in administrative matters

In 1680, when Denis Papin invented the pressure cooker, he was not concerned with a contribution to administrative planning Nevertheless, Papin's pressure cooker was an excellent model for the completely automated factory even though the cooker was an extremely primitive device, regulated only by the controlled utilization of escaping steam Papin's steam cooker differed only in sophistication from twentieth-century automated manufacturing processes The essential ingredients were and are the same, they are concerned with a closed system that utilizes feedback from its own operation in order to control future operations [2]

In this sense it also represented a first step in the direction of cybernetics Cybernetics was developed by Norbert Wiener and was first introduced to the scientific community in 1948 A highly quantitative concept, the essentials of cybernetics were concerned primarily with feedback and control

Papin's pressure cooker predated the steam engine by over a hundred years It was in 1799 that James Watt developed the first workable centrifugal governor for the steam engine [3]

The governor is mounted on a shaft by means of a collar that slides up and down depending upon the speed the governor is spinning Weights are mounted on the governor in such fashion that their centrifugal force will move the collar as the speed increases or decreases As the collar moves, it moves an arm that in turn moves a rod connected to a cut-off switch The motion of the rod cuts off power reducing the spin and changing the position of the collar back to its original position When the collar moves back to its original position, the rod moves accordingly Therefore, the power is renewed, and the cycle is initiated once again The steam engine is not a completely closed system because it needs fuel to continue running However, the operation of the governor is a closed system within that larger open system

The governor is an ideal analogue of a feedback system designed for automated control It represents constant monitoring of the activity of the system with resultant behavior modification according to the information fed

[2] R H MacMillan *Automation Friend or Foe?* New York The Cambridge University Press, 1956, p 7

[3] John F Sandfort *Heat Engines* New York Doubleday and Company, 1962, p 35

back from the system. It is through this type of model, which performs in a systematic fashion, that mathematical models can be built of the system. It is possible at this stage to build simulation models of extremely complicated systems and to study these systems under artificial conditions.

Throughout the period of time under consideration, two concurrent developments were taking place. There was considerable activity in the development of automated controls such as the steam engine and the governor, and there was also continuing interest in the development of computers. Although effective use of computers did not take place until the 1950's, various persons were preoccupied with the concepts and with attempts to develop computers.

Table 6.1 furnishes a chronology of the development of computers.

Table 6.1. Chronology of Computer Development

Babylonian mechanical surveying and mapmaking	3800 B.C.
Abacus	3000 B.C.
Greek Computer	100 B.C.
Napier's Bones	A.D. 1617
Oughtred's Slide Rule	A.D. 1632
Pascal's Calculator	A.D. 1642
Leibnitz's Calculator	A.D. 1694
Flyball Governor	A.D. 1788
Jacquard's Loom	A.D. 1804
Babbage's Difference Engine	A.D. 1812
Herman's Planimeter	A.D. 1814
Babbage's Analytical Engine	A.D. 1833
Kelvin's Harmonic Synthesizer	A.D. 1872
Hollerith Machine	A.D. 1889
MIT Differential Analyzer	A.D. 1931
Mark I	A.D. 1944
ENIAC	A.D. 1946
EDSAC	A.D. 1949
EDVAC	A.D. 1952

The British Museum exhibits clay tablets which contain land surveys taken between 2300 and 2100 B.C. These tablets include interpolation and measurement.

The abacus, which has been in use for approximately five thousand years, is still used quite extensively throughout the world, especially in the Orient (In 1946, a contest was held between a Japanese clerk using an abacus and an American clerk using a calculator The Japanese clerk won with the abacus)

A system of sticks known as Napier's Bones is designed in such fashion that by the use of the principle of logarithms and a proper arrangement of sticks the product of two numbers can be determined

By 1621, Oughtred had developed a combination of two sticks with which he was able to perform addition, subtraction, multiplication, and division This use of logs and antilogs furnished a continuous functioning computer The slide rule is still the most widely used computer

Charles Babbage's Difference Engine used the method of constant differences, which allowed the performance of successive additions and computation of polynomial functions The machine also printed-out the entire problem After 1833, Babbage began a design for an analytical engine The machine was to be more automatic than a difference engine and was to use punched cards It was never completed

The planimeter was developed by Herman and was built to solve the basic integration problem

$$A = \int_{x_1}^{x_2} y\,dx$$

The integral represents the area under the curve y from some point x_1 to x_2 The planimeter through a complex gear arrangement calculates the area under the curve by tracing the boundaries of the curve

The mechanical differential analyzer built by Vannevar Bush in 1931 was the first mechanical device for solving problems in differential calculus The machine was developed at MIT During the time that work was continuing on the development of computers, investigators were also exploring a more direct control mechanism

The thermostat, invented in 1830 by Anton Ure, is a sophisticated governor that utilizes temperature as the regulator source The thermostat that regulates household temperature illustrates the feedback principle and the practical applications of the concept By the use of a thermostat, the temperature regulation in a building becomes a part of a closed looped system controlled by preset numbers to start furnaces for heating purposes or air-conditioning for cooling purposes The center concept (automatic control) is continued

without direct human intervention by preset numbers that control the regulator within specified limits

Practical applications of the concept of automated control date back to 1833 when the Royal Navy partially automated mechanized biscuit making The motivation was primarily to relieve the human of tedious and repetitious tasks As the level of sophistication of automation increases, greater product uniformity and quality naturally result

Also illustrative of benefits other than the elimination of tedium is the concept of reliability that was introduced when Sir George Aire first built a speed regulator for his telescope Individual differences in speed control and recording are of considerable significance in astronomy, where precision is carried to extreme Present-day guidance systems in the military applications denote the refinements that have taken place since Aire's first piece of equipment in 1840

Over half a century before the automobile industry automated the assembly line and revolutionized American industrial methods, a Chicago meat-packing firm had established a monorail for transporting carcases during processing The continuous monorail in the meat-packing firm was put into operation in 1869 In 1930, Henry Ford initiated mass production into the automobile industry by establishing a chassis monorail and thereby automating the auto industry

Cybernetics

The term *cybernetics*, meaning literally "steersman" or "governor" was introduced formally into the scientific vocabulary in 1948, upon publication of Wiener's book *Cybernetics* The essential and distinguishing feature of the concept is that of feedback Such a system assumes an internal communication network such that constant monitoring of internal activities is going on and subsequent adjustments are made to the system The essence of cybernetics, therefore, is internal communication and control The concept of cybernetics has greatly enhanced scientific exploration and understanding of physical, biological, sociological, and psychological systems in addition to management information and control systems Widespread use of cybernetic theory has become commonplace in industry [4]

[4] Norbert Wiener *Cybernetics* New York Doubleday and Company, 1948

Physical Systems

The history of control systems presented above furnishes early documentation for the development of physical systems that were built upon the cybernetics concept long before the concept was formalized in the scientific literature

The governors for the steam engine and the common household thermostat are indicators of physical systems that utilize the cybernetics concept More sophisticated devices such as the gyrocompass used to steer ships and automatic pilots for air navigation are extensions of these more elementary devices Regardless of the level of sophistication, the function is essentially that of physical control of a mechanical process The main characteristics involve internal modification of function as the result of feedback from within the system

Biological Systems

The biological concept of *homeostasis* is illustrative of the biological functions that maintain stability and equilibrium within the body through a complex information system Biological information systems range in complexity from deoxyribonucleic acid (DNA) which comprises the basic genetic scheme for regulation and control to respiration, the mechanics of which are well known

The body is a self-contained information system that maintains internal integrity by constantly monitoring a complex biochemical system The nervous system represents the signal transmission facility whereby information can be fed back and acted upon to remedy any disturbance of equilibrium

A biological system is an excellent model for the study of any complex system Because the biological system is a dynamic and constantly monitored system, it is the ideal analogue for studying management systems

Sociological Systems

Investigations of sociological systems have had a very low yield in so far as basic principles or understanding of the dynamics of the systems are concerned Unfortunately the knowledge gained has been superficial and obvious

However, in those cases where quantitative methods have been utilized, considerable payoff has been promised

Most fruitful of the sociological systems studies have been the ones that are epidemiological in nature Although epidemiology is concerned with the study of disease, the models derived involve essentially analogues of systems whereby subsets of the systems are in contact with one another, and as a result of the contact some change takes place within the systems

One of the first of such studies, referred to earlier, consisted of developing a mathematical model of the fox and rabbit populations When rabbits (the food for foxes) become abundant, the fox population increases because of the abundance of food As the fox population continues to increase, it will after a time become so large that the rabbits (food supply) become scarce and the fox population begins to decline As the fox population continues to decline, it will become so small that the rabbits are not subjected to intensive destruction and hence will begin to increase in population As the rabbit population increases and hence furnishes more food for the foxes, the fox population again begins to increase and the new cycle begins

Psychological Systems

The mechanics of psychological systems as constantly adjusting functions are relatively well known Some of the better documented studies have been done by Selye on stress As a person responds to a stressful situation, there is a tendency to over respond to the situation As adjustment is made, the measureable responses again return to normal If the stress is too great, a catastrophic response results, and the behavioral repertoire breaks down Normal reaction is illustrated in Figure 6 1

In Figure 6 2 where a catastrophic response occurs, the organism can no longer adjust to the environment and the regulatory and control system is no longer adequate for appropriate functioning (Note The dotted lines in Figures 6 1 and 6 2 indicate normal tolerance levels)

Psychological systems have not been highly productive toward model building However, the adjustment mechanisms with which the organism adapts to its environment are obviously present Knowledge of the regulation and control of human behavior has fascinated leaders from the beginning of the human race Possibly it is still the major problem confronting an administrator

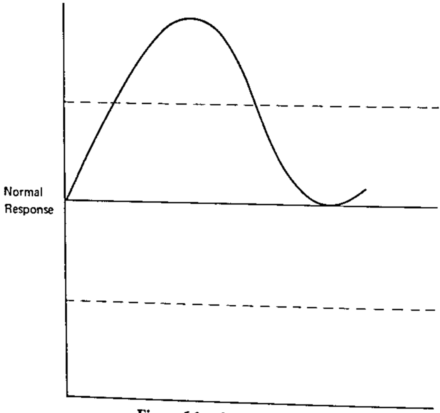


Figure 6.1. *Normal response.*

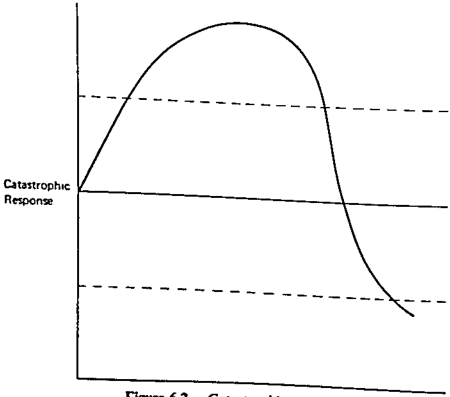


Figure 6.2. *Catastrophic response.*

Management Information and Control

The feasibility of an automated approach for management has been demonstrated in the paper and chemical industries, where major portions of plant operations are now under automated control The implications for management are obvious As automatic regulation and control of routine activities is introduced, a concomitant dividend occurs in the form of almost instant information about operation at one's finger tips

The impact of information systems and technology is long overdue in the field of education The administrator in education must make decisions based upon latest information about his system

Technology is now available to do so The availability of computers and the high level of sophistication of methodology appropriate to administrative planning and control opens an entirely new approach to many old administrative problems

A brief introduction to flow charting and PERT diagrams follows in the remainder of this chapter The brief treatment of flow charting and diagramming will serve as a background for the procedures used in PERT

Gantt Charts

Development of Gantt Charts began during World War I According to Gantt, early developments of the charts were initiated at the beginning of the war in the Ordnance Department under the direction of Brigadier General William Crozier, Chief of Ordnance [5] The primary purpose of those early charts was to match promises and performance The charts were designed to furnish management with overall control over program of war production

As work with charting increased, chart usage began to serve more effectively as an integrated information system Charts furnished management with a detailed record of production activities, thereby allowing a greater amount of long-range planning and control

Charts also furnished management with comparative and normative data concerning individual workers In this respect charts began to furnish management with continuous monitoring of worker performance [6]

[5] Alex W. Rathe, editor *Gantt on Management* Cambridge, Mass American Management Association, 1961, p 143

[6] *Ibid*, p 147.

Comparable charts were developed for machine record output also As charts were developed for the various subareas within an organization, it was only a matter of time before a detailed integrated information system was developed

The computerized information systems of today hold masses of data from various facets of the organization Such data are available for continuous monitoring of operation, administrative decision making, and research purposes

Gantt states that the two principles upon which charting methods were founded were

> First The fact that all activities can be measured by the amount of *time* needed to perform them
>
> Second The space representing the time unit on the chart can be made to represent the amount of activity which *should have taken place* in that time [7]

The essential importance of charts in the development of regulation and control lies in their systematic approach to the problem of control Only with systematic records can one begin to study and control operations in a complex system

Flow Charts

In any attempt at systematic regulation and control, an overall study of the system is necessary As a system of regulation and control is implemented, a general model of the system is required The first approximation to a general systems model usually takes the form of a flow chart

A flow chart is primarily a pictorial representation of the logical structure of organizational functions arranged in appropriate temporal sequence In this sense the flow chart is a detailed road map through which the organizational activities are required to flow

A relatively standard set of symbols has been adapted by persons doing flow charting Figure 6 3 presents the most frequently used set of symbols

Figure 6 4 furnishes additional information and identifies several commonly accepted symbols useful in data processing These symbols like

[7] *Ibid*, p 144

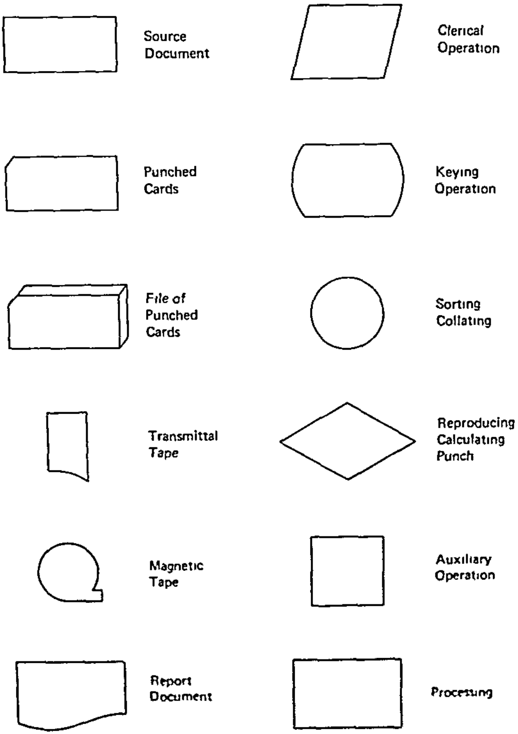


Figure 6.3. *Flow chart symbols*

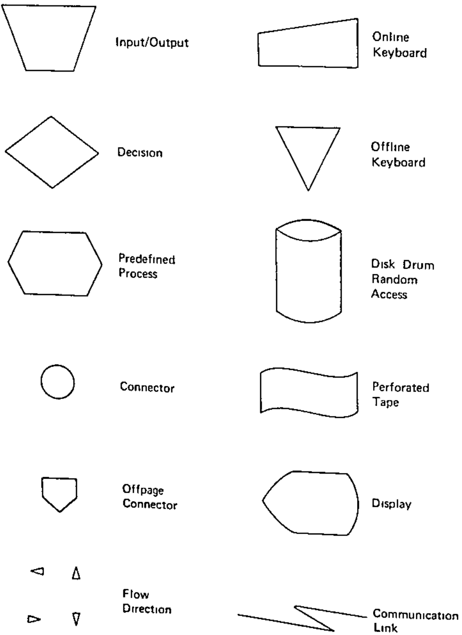


Figure 6.4. *Flow chart symbols.*

mathematical symbols have very special denotations Persons doing flow charting will find it useful to be consistent in the use of symbols from the beginning of their work

PERT and CPM

Modern management techniques concerned with monitoring and control of administrative operations can be traced to the Gantt charts and computer flow charts In 1956 the E I du Pont de Nemours Company initiated work on the applications of computers to problems of planning and scheduling Two engineers, in 1957 (Morgan Walker of DuPont, and James Kelley, Jr, of Remington-Rand) developed the Critical Path Method (CPM) as a direct result of the DuPont work Kelley and Walker presented a paper "Critical Path Planning and Scheduling" to the Eastern Joint Computer Conference in 1959 Also in 1957 the U S Navy Special Projects Office was given the responsibility for the management of Ballistic Missile Program, a large, sophisticated, weapon system which required the development of the nuclear submarine system POLARIS A solution to the complex management problem was developed jointly by the U S Navy Special Projects, Bureau of Ordinance, and the management consulting firm of Boaz, Allen, and Hamilton Formal presentation of the technique derived from the POLARIS project was reported in a technical document of the U S Navy Special Projects Office, Bureau of Ordinance in July, 1958, entitled "Program Evaluation Research Task Summary Report, Phase I and Phase II"

Although many descriptive acronyms emerged, such as SCANS, TRACE, MAPS, PEP, following the enthusiastic acceptance of PERT and CPM, the latter two acronyms have become reasonably standard

PERT Diagrams

The growing acceptance of systematic methods for operational control are evident in governmental agencies where large scale expensive contracts are let The Air Force, for example, requires (in many cases) bidders on large contracts to demonstrate management capability and complete administrative control by submitting a PERT diagram along with the original proposal [8] The application of PERT as part of the program is a sizable budgetary item

[8] "Move Up in Space—Win Points," *Business Week* (September 25, 1965), pp 92–103

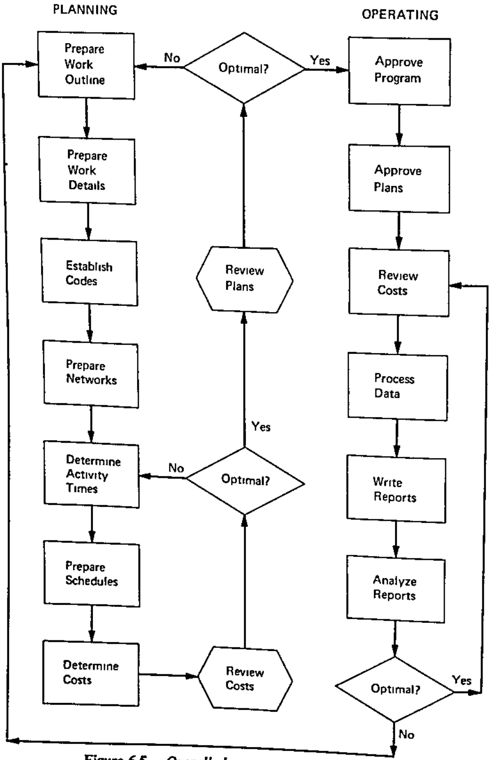


Figure 6.5. *Overall planning and operating phases*

The Glenn L Martin Company, when bidding on the Titan III missile contract, was awarded a preliminary grant of $14 7 million just to PERT the operations involved for completion of the project [9] Bonuses and penalties were set up on the basis of the PERT diagram

The overall planning and operating phases are illustrated in Figure 6 5 Through this type of network an administrator or contract proposal reviewer can simulate the work to be done on the contract In many cases trouble can be spotted before it occurs in the real work situation In all cases the diagram gives the viewer a general picture of the work to be performed, the sequence of events, and a firm concept of the costs involved

The following list of projects is offered as illustrative of the growing applications of PERT The list is taken from a document from Mauchly Associates and denotes the activities of a single firm [10]

Table 6.2

Name of school and architect	*Type of building or project*	Estimated *cost of work*
Glassboro State College Glassboro, New Jersey Merchant and Seidel	Arts Building, Dormitory and Library Addition	$2,000,000
Paterson State College Paterson, New Jersey Gilbert L Seltzer Paterson, New Jersey	Library and Classroom Building	$2,500,000
Cumberland County College Vineland, New Jersey Fulmer & Bowers Princeton, New Jersey	Five Building Complex	$5,000,000
Special Services School North Belmore, Nassau County, New York Frederic P Wiedersum Associates Valley Stream New York	Nine Unit Complex	$6,000,000

[9] *Ibid*

[10] Partial list of university, college, and public school construction projects planned, scheduled, and controlled with CPM (Critical Path Method), implemented by Mauchly Associates, Inc , Fort Washington, Pennsylvania, March, 1966

Name of school and architect	Type of building or project	Estimated cost of work
New York City Board of Higher Education Moore & Hutchins New York, New York	Staten Island Community College (This is a completely new college)	$10,000,000
Dormitory Authority State of New York I M Pei & Associates New York, New York	Two 30-Story Residence Towers for New York University, New York City	$7,500,000
University of Pittsburgh Pittsburgh, Pennsylvania Deeter, Ritchey & Sippel Pittsburgh, Pennsylvania	School of Engineering (G S A Project 1103-9)	$13,000,000
School District of Abington Township Caudill, Rowlett & Scott Houston, Texas	New High School consisting of four separate buildings	$7,500,000
Western Reserve University Cleveland, Ohio Barnes, Neiswander & Associates Cleveland, Ohio	Pre-planning and scheduling of Design and Pre-Bid Stage for Medical School, Dental School, Nursing School and supporting facilities CPM is being applied to schedule all work required to establish the earliest possible bid dates on all projects	$50,000,000
Upper Merion School District King of Prussia, Pennsylvania Howell, Lewis, Shay & Associates Philadelphia, Pennsylvania	Junior High School	$3,125,000
Alexandria City Public Schools Alexandria, Virginia Saunders & Pearson Alexandria, Virginia	T C Williams High School	$4,000,000
Denver Public Schools Denver, Colorado Buell & Company Denver, Colorado	J F Kennedy Jr -Sr High School	$4,000,000

Name of school and architect	Type of building or project	Estimated cost of work
Union Free School District #2 Irvington, New York Caudill, Rowlett & Scott Houston, Texas	Irvinton High School	$2,000,000
Gateway Union School District Monroeville, Pennsylvania Walter E Schardt & Associates Pittsburgh, Pennsylvania	Gateway Senior High School	$1,200,000
Pennridge Joint School District Perkasie, Pennsylvania Micklewright & Mountford Trenton, New Jersey	Pennridge Jr High School Addition	$2,500,000
New Haven Public Schools New Haven, Connecticut Perkins & Will-Carlton Granbery White Plains, New York New Haven, Connecticut	Quinnipaic K-4	$500,000
Long Branch Junior High School Long Branch, New Jersey Fessler, Boyken & Moss Hazlet, New Jersey	Long Branch Jr High School Addition	$2,500,000
University of Massachusetts Amherst, Massachusetts Campbell, Aldrich & McNulty Boston, Massachusetts	Administration Building	$2,500,000
Syracuse University Syracuse, New York	St Mary's Dormitory Project Men's Dormitory Women's Dormitory Commons Building Underground Garage	$6,000,000
Sisters of Charity Scholastic Novitiate School Wellesley Hills, Massachusetts Whelan and Westman Boston, Massachusetts	Two Four-Story Wing Structure with One-Story Central Chapel	$2,500,000
State University Construction Fund	State University College Oswego, New York	$12,000,000

Name of school and architect	Type of building or project	Estimated cost of work
State of New York Skidmore, Owings & Merrill New York, New York	Four Buildings	
Monroe Community College Rochester, New York Caudill Rowlett & Scott Houston, Texas Barrows, Parks, Morin, Hall & Brennan Rochester, New York Ribson and Roberts Rochester, New York Todd and Giroux Rochester, New York	New Campus—11 Buildings	$15,000,000

PERT Terminology

Certain definitions and symbols are used with considerable frequency in the Program Evaluation and Review Technique This section on the most commonly used terms and symbols in the program will furnish the potential PERT user with the necessary tools needed to construct a PERT network

The essential purpose of a *flow chart* is to lay out (in logical form) the basic ideas with which one will be involved in the completion of a task The flow charting idea grew from work with Gantt Charts and was essentially an engineering device allowing the engineer to arrange his work in a carefully ordered sequence that followed the logical development of an engineering task

The flow chart procedure is used extensively by computer programmers Indeed, one of the first things a neophyte programmer learns is how to flow chart or build a flow diagram of the problem to be programmed Flow charting assures that all housekeeping details will be taken care of in the most logical sequence of the problem It is in this respect that PERT uses flow charting

We might illustrate use of flow charting by teaching extraction of the square root of a number An iterative procedure is used that minimizes the number

1	Pair the digits from right to left	1 24 58
2	*Guess at the most likely root*	1 1 0
3	Divide No 1 by No 2	(12458) / (110) = 113
4	Add No 2 to No 3	110 + 113 = 223
5	Divide No 4 by 2	*(223) / 2 ≈ 111 5*
6	Divide No 1 by No 5	(12458) / (111 5) ≈ 111 7
7	*Add No 5 to No 6*	*111 5 + 111 7 = 223 2*
8	Divide No 7 by No 2	(223 3) / 2 = 111 6
9	Divide No 1 by No 8	(12458) / (111 6) ≈ 111 6

Figure 6 6. *Flow chart for finding square root*

of steps involved For example, find the square root of 12,458 to the nearest tenth The flow chart in Figure 6 6 furnishes logical steps by which one proceeds When the divisor and quotient are equal, the answer has been obtained This flow chart could be used for any number so long as one follows the logical sequence of steps

In a PERT diagram an *event* is symbolized by a circle as in Figure 6 7 Each event in a PERT diagram denotes a significant occurrence of some task

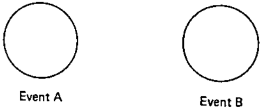


Figure 6 7. *Event*

required for completion of the job under consideration The event does not require time, it is considered to be an instantaneous occurrence An event circle comprises the physical structure of a PERT diagram and symbolizes every detail which must be completed

Although a PERT diagram can include thousands of events, there is a single event in all diagrams that marks the onset of that particular job Because an *onset event* does not require time, the earliest expected date of completion is given as zero The following diagram illustrates the onset event

The PERT diagram is read from left to right The first circle on the left denotes the onset event If Figure 6 8 be the plans for a new school building, the onset event will denote formal approval for the building

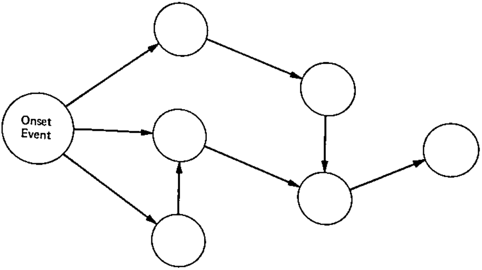


Figure 6 8 *Onset event*

The *end event*, shown in Figure 6 9, is the objective toward which all of the other activities and events are directed It indicates the completion of the project Since the end event is the last event on the right of the entire PERT

diagram, it denotes that all other events must be completed before the end event can be.

Again, if Figure 6.8 represents the working plans for a new school building, the end event will designate completion of the building in all respects. The building will be ready for the first day's classes.

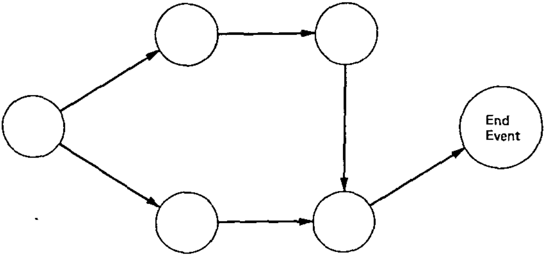


Figure 6.9. *End event.*

As noted above, events do not require time. However, activities do require time. Activities are portrayed in the PERT diagram by arrows that link the events. This activity path is illustrated in Figure 6.10, which shows a set of events A to H that must be completed. In order for event B to be completed,

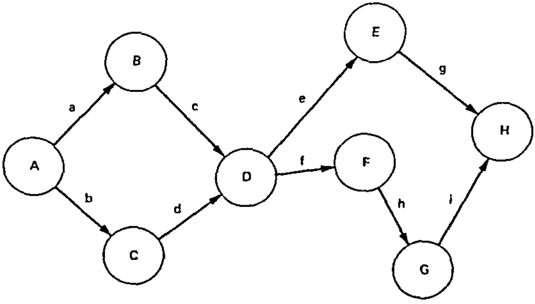


Figure 6.10. *Activity path.*

event A must be completed The time for B to be completed after A has been completed is equal to a In like fashion it takes d units of time to complete D after C has been completed The minimum time within which D can be completed is either a + c or b + d, whichever is greater

Although all activities require some period of time for completion, not all paths require time lapses between events The requirement exists that events be listed to be certain that they are completed If no time elapses between events then a *dummy path* is inserted into the PERT diagram The dummy path of Figure 6 11 is portrayed by a broken line arrow between two events and is assigned zero time Event D must be completed before or simultaneously with event F, or it can be done simultaneously with or after event C

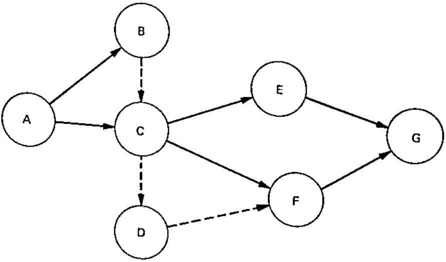


Figure 6 11 *Dummy path*

Predecessor and successor events have obvious meanings The predecessor event is that event which comes before another event, the successor event is that event which follows another event The importance of their identification lies in (a) the logical sequence of events and (b) the time elapsing between events Figure 6 12 depicts two events A and B, which are fragments of a PERT network

The message derived from Figure 6 12 states that the direction of activity

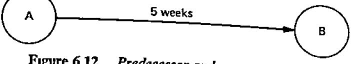


Figure 6 12 *Predecessor and successor events*

is from A to B and the time elapsing for the completion of B after A has been completed is five weeks

Numerals used in *numbering events* throughout a network are nominal numerals That is, they serve the purpose of naming each event and need not necessarily be in numerical sequence This concept is illustrated in Figure 6 13

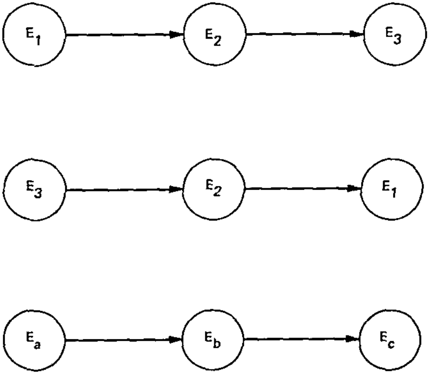


Figure 6 13 *Numbering events*

In Figures 6 11, 6 12, and 6 13, the activity arrow denotes the direction of flow The numerals or letters merely identify events

A *network* is an extension of the flow chart concept In effect, it is a blueprint of tasks to be completed on a given job

A PERT network is a step by step enumeration of detailed events and activities arranged in proper sequence and stipulating time requirements for each task completed Figure 6 14 denotes a typical PERT network

PERT network events may number in the thousands Permutations of possible routes from A to J, J = 1 1000*n*, pose considerable time problems in terms of calculations Fortunately computers have practically eliminated the calculation tedium

The primary contributions of a PERT network are (a) *to furnish planning personnel with time and sequence aspects of activities and events* and (b) *to show the interrelatedness of the many events*

As indicated above, the number of possible routes through a network is equal to the possible permutations of paths Although there may be hundreds of paths in a given network, there is one *critical path* for each network The critical path is the route through the network that takes the *maximum* time to traverse the network from onset event to end event As a matter of convention, the critical path is charted on the PERT network by using double

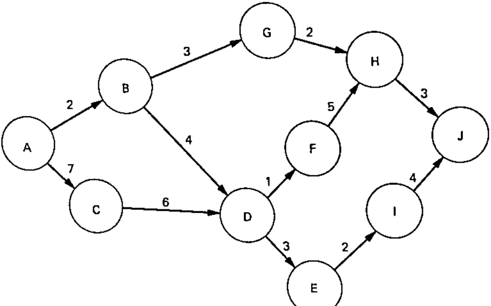


Figure 6 14 *PERT network*

lined arrows ⇒ for those activities lying on the critical path Determination of the critical path for the network is shown in Figure 6 15

The objective in finding the critical path is to find the maximum time for traversing the network from A to J One merely sums the activity times to each event from all possible routes and retains the maximum summed time There is only one route from A → B, and the time is two weeks There is only one route from A → F, and the time is 2 + 5 = 7 weeks However, from A → G one could go A → B → F → G or A → B → D → G In the former the time elapsing would be 2 + 4 + 2 = 8 weeks in the latter the elapsed time would be 2 + 5 + 4 = 11 weeks Continuing for A → I, the following routes could be used A → B → F → I, A → B → F → G → I, A → B → D → G → I The respective times are 2 + 4 + 3 = 9, 2 + 4 + 2 + 2 = 10, 2 + 5 + 4 + 2 = 13 The earliest expected time is thirteen weeks from A → I All possible routes are indicated below

(1) $A \rightarrow B \rightarrow F \rightarrow I \rightarrow J = 2 + 4 + 3 + 3 = 12$
(2) $A \rightarrow B \rightarrow F \rightarrow G \rightarrow I \rightarrow J = 2 + 4 + 2 + 2 + 3 = 13$
(3) $A \rightarrow B \rightarrow D \rightarrow G \rightarrow I \rightarrow J = 2 + 5 + 4 + 2 + 3 = 16$
(4) $A \rightarrow B \rightarrow D \rightarrow E \rightarrow H \rightarrow J = 2 + 5 + 6 + 2 + 4 = 19$
(5) $A \rightarrow C \rightarrow E \rightarrow H \rightarrow J = 3 + 1 + 2 + 4 = 10$

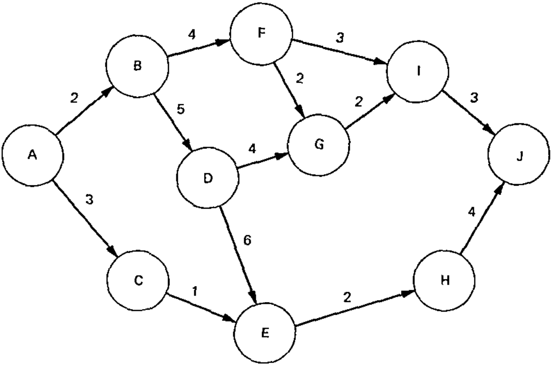


Figure 6.15. *PERT network.*

The earliest expected time elapsing between $A \rightarrow J$ is via the path $A \rightarrow B \rightarrow D \rightarrow E \rightarrow H \rightarrow J$ and is equal to nineteen weeks Figure 6 15 can be redrawn as in Figure 6 16 which is complete with critical path

The total PERT network is made up of all detailed events which must be completed before the project is completed Every significant event should be listed so that, at the operational level, the event is certain to be completed at the proper time and at the proper cost

PERT is a management tool and as such, different levels of management are concerned with different major events Hence, when the PERT network is reported to management, certain events take on more significance to a specific management level The major events that represent major completion of activities are called *Milestones* Milestones can be considered to represent an abridged PERT network that has had many detailed events omitted Only the major events (milestones) remain that permit a view for management of the total-project time schedule

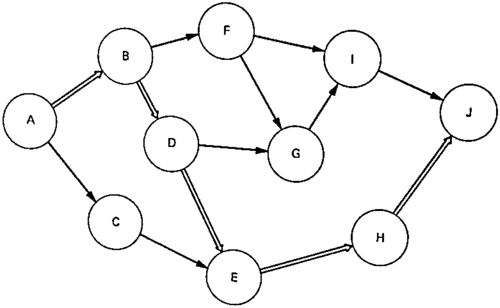


Figure 6 16 *Network with critical path*

In the majority of projects the total PERT network requires intimate knowledge about details of tasks to be completed and particularly of time lapses between events Therefore, PERT networks are usually constructed by teams concerned with a separate subnetwork After each subnetwork is completed, all of the subnetworks must be merged into an overall operating network The term *interface* specifies where and how the merging will take place

As an example, consider the possibility that one might be concerned with planning a new junior college Subnetworks of an overall PERT network might consist of building, staff, students personnel, instructional program and major financial, and administrative decisions Figure 6 17 contains milestones from the major administrative decision network Figure 6 18 contains milestones regarding the subnetwork of staff

Events E_3 and E_5 of Figure 6 17 and events E_1 and E_5 of Figure 6 18 denote the same milestones Therefore, the two subnetworks would interface

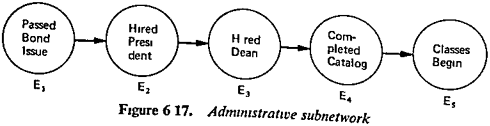


Figure 6 17. *Administrative subnetwork*

Figure 6 18 *Staff subnetwork*

at E_1 and E_3 of Figure 6 17 and Figure 6 18 respectively and E_5 and E_5 of the two subnetworks

If data are entered into a computer, the computer (since the two interfacing events are the same and carry the same identification) will automatically merge the two subnetworks into a single operational network.

After the PERT network is completed, it becomes necessary that time estimates be made for time lapses between events Such estimates require considerable knowledge about details of an activity to be completed They should be made only by someone intimately familiar with the detailed operations of the project

Three time estimates are made for each activity These three time estimates are referred to as *the most optimistic time*, *the most pessimistic time*, and *the most likely time*

The most optimistic time estimate is that time which will elapse between two events if everything goes perfectly The MOT assumes no delays, no labor problems, no shortage of materials or any other problem that might interfere with the completion of the particular event

The most pessimistic time estimate assumes the validity of Murphy's Law, that is, "If anything can go wrong, it will "

The most likely time estimate assumes a normal amount of delay with no really major problems causing a delay in event completion

The usual notation given for the three time estimates are *a* for the most optimistic time estimate, *b* for the most pessimistic time estimate and *m* for the most likely time estimate

The three time estimates, *a*, *b*, *m*, furnish the planner with a "best estimate" of time lapses and are used for calculating variability and making probability statements

Some computer programs take only one time estimate as input However, for purposes of calculating probabilities, the use of three time parameter estimates is required

Expected elapsed time between events is referenced by the symbol t_e and is derived from the time parameters a, b, m In equation form—

$$t_e = \frac{a + 4m + b}{6}$$

Obviously the formula for t_e is a weighted average for the three time parameters

a is given a weight of 1,
b is given a weight of 1,
m is given a weight of 4

Since the above weighting scheme uses the equivalent of six parameters, one must divide their sum by six in order to determine the average That is, the formula for t_e is a straightforward application of the mean formula

$$X = \frac{\sum X}{n}$$

As noted above, some computer programs do not use three time estimates; but one can assume that the time estimate between events will be more reliable if three time estimates are made

Estimates of the two parameters *mean* and *standard deviation* assume a normal distribution approximated by a Beta distribution The shape of this distribution is given in Figure 6 19, which illustrates a unimodel time distribution with the expected time t_e estimated by

$$t_e = \frac{a + 4m + b}{6}.$$

The area covered by three standard deviations on either side of the mean in a normal distribution includes all but 0014 of the distribution Since the Beta distribution is an approximation of the normal distribution, it is safe to assume that six standard deviations would include all but an insignificant amount of the area under the normal curve shown in Figure 6 20

Obviously $3\sigma t_e$ and $-3\sigma t_e$ are on the outer limits of the distribution in Figure 6 20 The area between $3\sigma t_e$ and $-3\sigma t_e$ includes almost all of the area under the curve in Figure 6 20 Since there are six σt_e's over the entire distribution, the range is merely the difference between $3\sigma t_e$ and $-3\sigma t_e$ divided by six

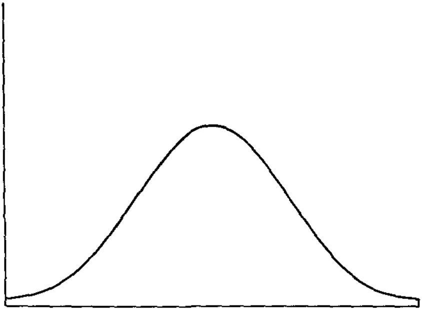


Figure 6.19. *Normal distribution*

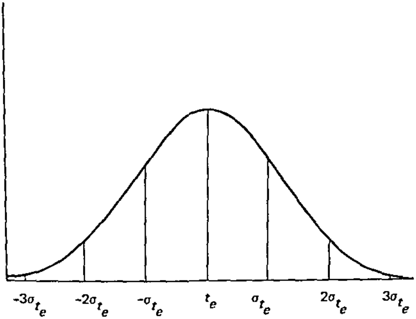


Figure 6.20. *Normal curve*

Since $3\sigma t_e$ is the outer limit in the *positive* direction, it must represent the most pessimistic time for completion of t_e, but the most pessimistic time for completion of t_e is equal to b

Since $-3\sigma t_e$ is the outer limit in the *negative* direction, it must represent the most optimistic time for completion of t_e; but the most optimistic time for completion of t_e is equal to a

Substituting $3\sigma t_e = b$ and $-3\sigma t_e = a$ and dividing by six (the number of σt_e's) gives—

$$\sigma t_e = \frac{b-a}{6}.$$

Interestingly, σt_e is the independent of t_e See Figures 6 21, 6 22, 6 23. In Figure 6 21, $t_e = 7$, $a = 5$, $b = 17$ Therefore,

$$\sigma t_e = \frac{b-a}{6} = \frac{17-5}{6} = 2$$

In Figure 6 22, $t_e = 11$, $a = 5$, $b = 17$ Therefore,

$$\sigma t_e = \frac{17-5}{6} = 2$$

In Figure 6 23, $t_e = 15$, $a = 5$, $b = 17$ Therefore,

$$\sigma t_e = \frac{17-5}{6} = 2.$$

In each of the distributions in Figures 6 21, 6 22, 6 23, the standard deviation remained at 2 However, the mean fluctuated considerably

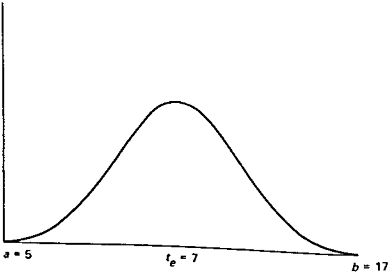


Figure 6.21. *Normal curve.*

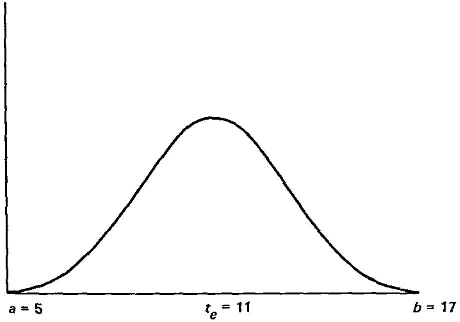


Figure 6.22. *Normal curve.*

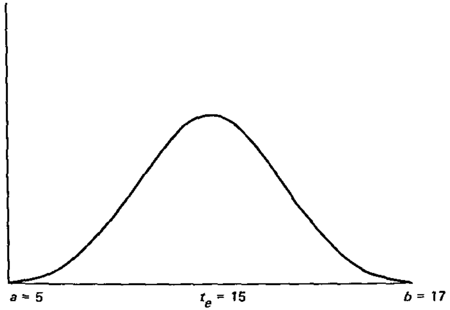


Figure 6.23. *Normal curve*

The approximations used in PERT might be cause for concern by some readers. Indeed, no rigorous proof has been given regarding the suitability of the Beta distribution as an approximation of the normal distribution as used in PERT. However, empirical evidence consistently suggests the degree of accuracy is appropriate considering other assumptions and approximations in the application of PERT.

The *earliest expected time* T_E is the required time between two events after all preceding events have been completed. Figure 6.24 contains several paths to event G.

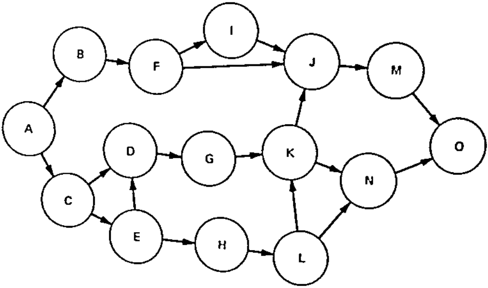


Figure 6.24. *PERT network*

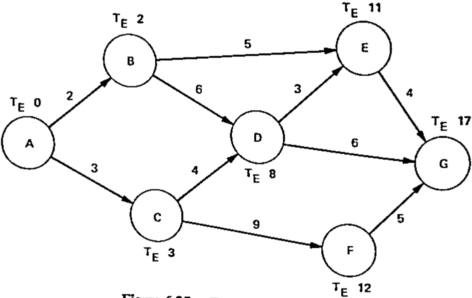


Figure 6.25. *Earliest expected time.*

The path A → C → D → G has a time lapse of $1 + 1 + 3 = 5$ time units The path A → C → E → D → G has a time lapse of $1 + 3 + 2 + 3 = 9$ time units Therefore, the earliest expected time (T_E) for completion of G is 9 time units The T_E for any given event is equal to the sum of the T_E's for the preceding events When first learning PERT networking, it is usually advisable to record the T_E's as in Figure 6 25

Figure 6 25 shows 17 time units to be the minimum time in which one can traverse from A to G and still complete all of the preceding events

A summary of the time lapses for the given paths in Figure 6 25 is presented below

A → B → E → G · 2 + 5 + 4 = 11
A → B → D → E → G : 2 + 6 + 3 + 4 = 15
A → B → D → G . 2 + 6 + 6 = 14
A → C → D → E → G 3 + 4 + 3 + 4 = 14
A → C → D → G . 3 + 4 + 6 = 13
A → C → F → G . 3 + 9 + 5 = 17

The term *latest allowable time* (T_L) is that time beyond which penalties or other serious consequences occur if the event is not completed In determining the earliest expected time, the procedure is to begin at the onset event on the left of the network and proceed to sum the activity times as in Figure 6 25 In determining latest allowable times, one begins at the end event and proceeds to subtract the activity times as in Figure 6 26 Figure 6 27 summarizes the latest allowable time information given in Figure 6 26

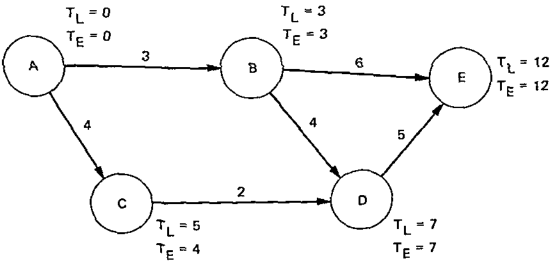


Figure 6 26. *Latest allowable time*

Note in Figure 6 27 that pairs of T_L's and T_E's throughout the network are equal This occurs at events A, B, D and E The significance of this occurrence is that these particular events are on the critical path Control of the entire process is dependent to a considerable extent on the determination of T_L's and T_E's The difference between these two numbers at a given event furnishes information about the time criticality factor

Slack refers to the difference between the latest allowable time (T_L) and the earliest expected time (T_E),

$$S = T_L - T_E$$

Slack time can be either positive, negative or zero depending upon the relationships ($T_L > T_E$) ($T_L < T_E$) ($T_L = T_E$) If $T_L > T_E$ then S is positive and there will be no delay in the completion of the event If $T_L < T_E$, then S is negative and there will be a delay in the completion of the event

Slack time furnishes the administrative monitor with information regarding possible trouble areas before they occur It does not prevent the trouble, but it alerts management to the problem

Unless there are good and sufficient reasons for doing otherwise, the end event T_L is set equal to the end event T_E If $T_L = T_E$ at the end event, then the slack S will be zero for all events along the critical path as illustrated in Figure 6 28 The critical path in Figure 6 28 is A ⇒ B ⇒ D ⇒ F ⇒ G

T_E at E = 12	T_L at D = 7
B → E = 9	A → D = 7
∴ T_L at B - 3	∴ T_L at A = 0

Figure 6 27. *Latest allowable time*

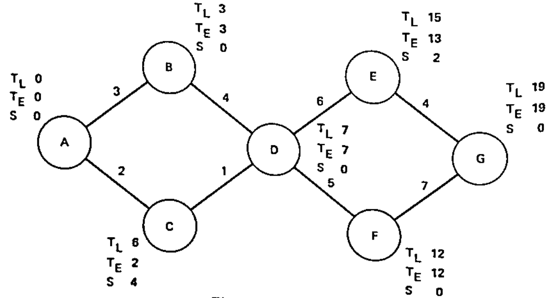


Figure 6.28. *Slack*

Replanning

Replanning is required in a PERT network if negative slack will cause serious consequences as a result of the delay Assume that T_L in the end event of Figure 6 28 is not equal to 19 but is equal to 17 as in Figure 6 29

If $T_L = 17$ is the latest allowable date and cannot be changed, then some replanning must take place throughout the network There are three routine methods of handling replanning problems (a) parallelism, (b) resource addition, (c) event elimination

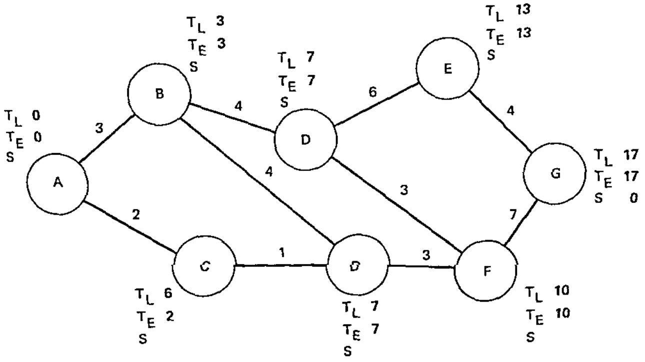


Figure 6 29 *Paralleling*

(a) *Parallelism* Adjustments can be made in the time requirements by replanning specific events so that the events can be carried out in parallel Figure 6 29 is a modification of Figure 6 28 in the form of paralleling

By subdividing D into D and D' and running the subdivided tasks simultaneously, two weeks has been saved and no delay in the final event G need take place Many variations of paralleling can be done in addition to this rather simple and straightforward example

(b) *Resource Addition* Adding resources such as additional personnel or equipment is probably the most simple administrative solution to making up

time However, when cost factors are taken into consideration, the time-cost trade-off may not be satisfactory If the cost factor is not prohibitive, then one needs to look at the entire network and merely speed up the activity time at the place or combination of places that would accomplish the desired reduction in time and at the same time minimize the increase in cost Reference to Figure 6 28 suggests several places where the two-week slack time could be made up

(c) *Event Elimination* In large-scale projects where the major goals can be achieved, the elimination of certain subgoals might be most appropriate In most large-scale building projects, for example, decisions must be made regarding the extent of the building program Usually some flexibility is maintained with elimination of some of the smaller aspects of the building program when financial problems arise

The primary contribution of PERT rests with the technique furnishing administrative personnel with continuous monitoring of project activities or updating As information continues to flow in from project activities, certain modifications are made in the time factors The frequency with which PERT programs are simulated or time dimensions run out will vary according to the nature of the project In a building program that is actually underway, perhaps weekly changes will be required On the other hand, if long-range planning is the project, then monitoring of the project could be done at less frequent intervals

PERT networks and time estimates are subject to errors because the time estimates are based upon the "judgments" of those persons who construct the PERT network Since errors are involved, predictions based upon PERT time estimates are subject to variation As in statistical decision making variability per se is not a problem if one can predict the limits within which the projected outcome is likely to fall In this respect the predictions made from PERT networks are probabilistic or stochastic in nature

By definition the *probability* of an event occurring is equal to the fraction of those events favorable to the given outcome divided by the total number of outcomes possible In symbolic language

$$P_{(e)} = \frac{e}{N}$$

where $P_{(e)}$ is read as the probability of e, and e, as the events favorable to

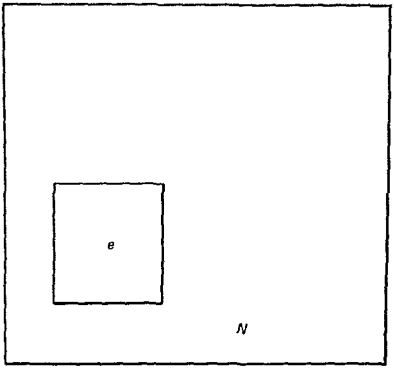


Figure 6.30. *Venn diagram.*

outcome e; and N, as the total number of events. Figure 6.30 shows the concept in terms of a Venn Diagram.

The area within the small rectangle e contains all points favorable to outcome e whereas N contains all points within the large rectangle. Obviously e is contained in N. (Only those points within the large rectangle are relevant, the small rectangle e can diminish in size to 0 and increase in size to N, and further since

$$P_{(e)} = \frac{e}{N}$$

then $P_{(e)}$ must always be within the limits 0 and 1 as e varies between 0 and N), that is, $0 \leq P_{(e)} \leq 1$ as $0 \leq e \leq N$.

Extending the concept of probability to the PERT network, the desirable probability concerning events can be determined. That is, the administrator concerned about the probability that a given event E will be completed on time can indeed make such a determination.

In a preceding section it was noted that for an activity standard deviation to be calculated, three time estimates were necessary: a, b, and m. Further, the time estimates a and b were used in calculating the activity standard

deviation as follows

$$\sigma t_e = \frac{b-a}{6}$$

Standard deviations or variances are additive One can, therefore, generate an event standard deviation as the result of addition, that is,

$$\sigma T_E = \sqrt{\sigma a^2 + \sigma b^2 + \quad \sigma n^2}$$

where T_E = event standard deviation and $n^2 \equiv n$th activity variance Consider Figure 6 31 The activity standard deviation for Figure 6 31 is given by

$$\sigma t_e = \frac{b-a}{6} = \frac{14-2}{6} = \frac{12}{6} = 2$$

where $b = 14$ and $a = 2$

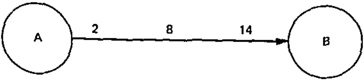


Figure 6.31 *Event*

Now consider Figure 6 32 The event standard deviation for C in Figure 6 32 is given by

$$\sigma T_E = \sqrt{\left(\frac{b-a}{6}\right)^2 + \left(\frac{b-a}{6}\right)^2}$$

$$= \sqrt{\left(\frac{20-2}{6}\right)^2 + \left(\frac{30-6}{6}\right)^2}$$

$$= \sqrt{3^2 + 4^2}$$

$$= \sqrt{9 + 16}$$

$$= 5$$

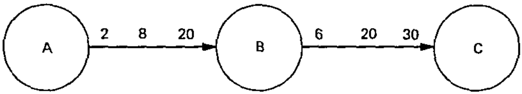


Figure 6.32. *Event*

In order to illustrate the determination of the probability of completing event C, one can invoke a familiar formula from elementary statistics, that is,

$$z = \frac{X - \overline{X}}{s}$$

where $X \equiv$ any score
$\overline{X} \equiv$ mean of the distribution
$s \equiv$ standard deviation

The z formula is a normalizing function that expresses the scores of a distribution in terms of standard deviation units or as deviation scores from the mean of that particular distribution

The z distribution is a normal distribution, hence, one can readily determine the probability of a score being equal to or greater than any score in the distribution by converting to a z score and referring to Table 9 4

For example, assume a distribution with mean equal to 50 and a standard deviation equal to 10 What is the likelihood that a score selected at random will be greater than 60? In other words, what is the probability that any score selected at random will be in the shaded area of the curve in Figure 6 33

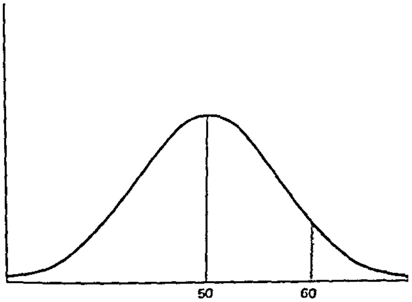


Figure 6.33 *Normal curve.*

Just convert the score of 60 to a z score,

$$z = \frac{60 - 50}{10} = \frac{10}{10} = 1$$

From Table 4 4 one finds that the area between the mean and one z unit is equal to 3413 Since 5000 of the curve lies above the mean, then the shaded area (which lies above one z unit) must be equal to 5000 − 3413 = 1587 Therefore, the probability that any score selected at random will fall above 60 is equal to 1587

The reader will also recall from elementary statistics that the t distribution is normally distributed and indeed as n becomes large, the t distribution converges with the table for z The formula for t is given by

$$t = \frac{(\bar{X}_1 - \bar{X}_2)}{\sqrt{(\sigma_{\bar{X}_1})^2 + (\sigma_{\bar{X}_2})^2}}$$

where $X_1 \equiv$ first mean
$X_2 \equiv$ second mean
$\sigma X_1 \equiv$ standard error of the first mean
$\sigma X_2 \equiv$ standard error of the second mean

Technically one should use the table for t when n is small However, PERT users traditionally use the table for z, and it will be assumed here that (considering the nature of PERT time estimates) the z table will be used Therefore, the formula for calculating probabilities is given as

$$z = \frac{T_L - T_E}{\sigma_{T_E}}$$

where $P_{(e)}$ = Probability of completing event e at estimated time
$T_L \equiv$ latest allowable date
$T_E \equiv$ earliest expected date
$\sigma_{T_E} \equiv$ event standard error
where

$$\sigma_{T_E} \equiv \sqrt{\sigma_1^2 + \sigma_2^2 + \quad \sigma_n^2}$$

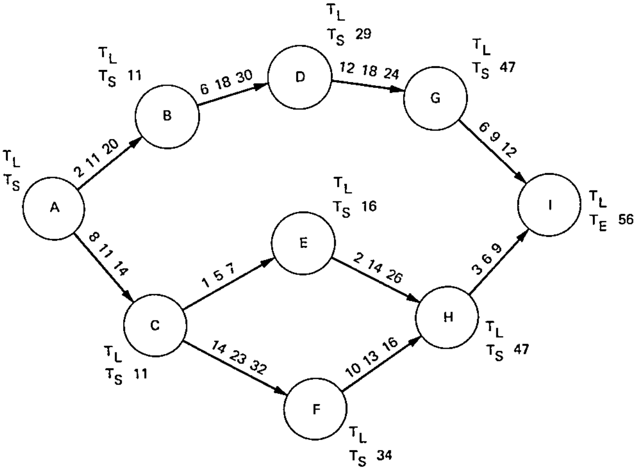


Figure 6 34 *PERT network*

As an example, consider the following network in Figure 6 34 The administrator is concerned primarily with the critical path in Figure 6 34 and specifically the probability that the scheduled date for completion of the project will be met This assumes that one needs to determine a probability number concerning the end event I One proceeds as follows First determine the critical path for the entire network The critical path is found to be $A \Rightarrow B \Rightarrow D \Rightarrow G \Rightarrow I$, and the earliest expected date is $11 + 18 + 18 + 9 = 56$ Assume that the scheduled date is 58 weeks Next compute T_r

$$T_r = \sqrt{\left(\frac{20-2}{6}\right)^2 + \left(\frac{30-6}{6}\right)^2 + \left(\frac{24-12}{6}\right)^2 + \left(\frac{18-6}{6}\right)^2}$$

$$= \sqrt{3^2 + 4^2 + 2^2 + 2^2}$$

$$= \sqrt{33} \simeq 5\ 75$$

Since

$$z = \frac{T_L - T_E}{T_E}$$

Then

$$z = \frac{58 - 56}{5\ 75} = \frac{2}{5\ 75}$$

The geometry of the situation is given in Figure 6 35 From Table 9 4, one can find that the area lying between T_E and T_L is equal to 1368 Since the entire area to the left of T_E is equal to 5000 and the area between T_E and T_L is 1368, then the area to the left of T_L is $5000 + 1368 = 6368$ The probability of completing the project at the scheduled date is 6368

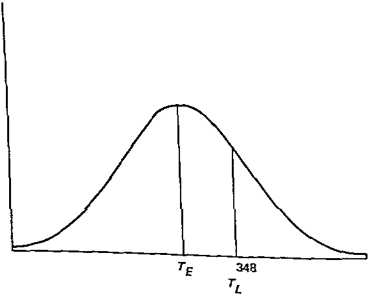


Figure 6.35 Normal curve

Appendices

Administrative Milestones

1 Bond Issue completed
2 Boards held joint meeting

3 Architect hired
4 Community survey completed
5 Temporary planning completed
6 Site designated
7 State Junior College Advisory Board
8 State department approval received
9 Lively Technical Institute brief completed
10 Resolution presented to Legislature
11 Legislative action taken
12 Fidelity Bond obtained
13 Consultant hired
14 Long-range enrollment projected
15 Final plans approved for Lively
16 Preliminary drawings completed, Lively
17 Educational specifications committee approved
18 Preplanning funds completed
19 Financing for Building Lively completed
20 Final plans approved
21 Preliminary drawings completed
22 Educational specifications completed
23 Architect hired
24 Advisory Board appointed
25 First year enrollment projected
26 Bids submitted Lively
27 Financing for Building completed
28 Capital budget completed
29 Comparative study completed
30 Bids accepted for building Lively
31 Bids submitted
32 Financial policy developed
33 President hired
34 Contracts awarded Lively
35 Bids accepted for building
36 Purchasing policy determined
37 Public relations director implemented
38 Lively conflict resolved
39 Temporary office space obtained
40 Permanent buildings completed Lively
41 Contracts awarded
42 Accounting system developed
43 Dean hired
44 Secretary hired

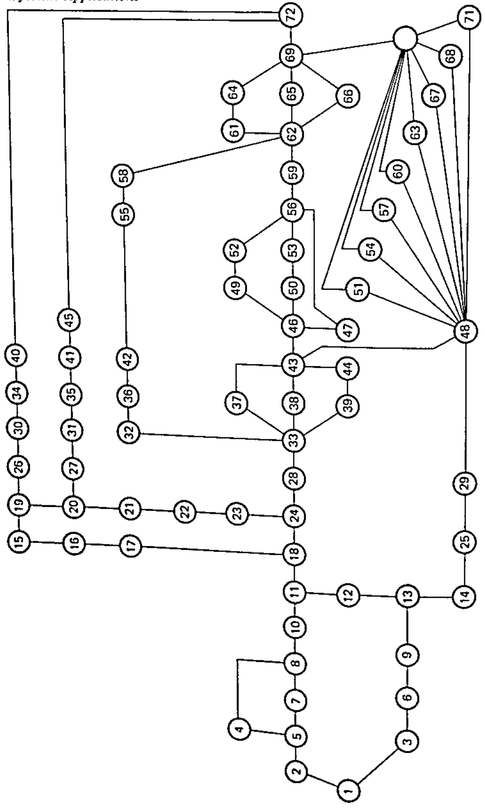


Figure 6 36. *Administrative milestones*

45 Permanent buildings completed
46 Salary schedule established
47 Number of nonprofessional personnel determined
48 Temporary buildings selected
49 Number of administrators determined
50 Number of instructors determined
51 Administrative facilities determined
52 Administrators selected
53 Instructors selected
54 Faculty facilities determined
55 Financial forms developed
56 Operational budget completed
57 Guidance facilities determined
58 Insurance arranged
59 Tuition and fees determined
60 Study areas selected
61 Registration procedures completed
62 Receipt of funds begun
63 Library facilities determined
64 Administrators appointed
65 Instructors appointed
66 Nonprofessional personnel appointed
67 Dining facilities determined
68 Student health center selected
69 Classes begun in temporary buildings
70 Temporary spaces ready
71 Student Center completed
72 Classes begun in permanent buildings

Personnel

1 Retirement policy established
2 Director of Evening Division selected
3 Classes begun
4 Holidays determined
5 Procedures for faculty promotions established
6 Faculty oriented
7 Travel policy established
8 Number of teachers in each field determined
9 New campus selected
10 Librarian appointed
11 Organization chart completed

12 Faculty speakers bureau established
13 Workmen's compensation established
14 Personnel record system completed
15 Faculty absences policy established
16 Administration appointed
17 Department Heads selected
18 Staff evaluation criteria established
19 Dean hired
20 Maintenance staff selected
21 Faculty sponsors of student activities completed
22 Nonprofessional job classification made
23 Instructors appointed
24 Permanent and ad hoc committees set up
25 Nepotism policy established
26 Salary schedule completed
27 Campus parking regulations established
28 Faculty in service education established
29 Librarian selected
30 Office space assigned to staff
31 Business Manager selected
32 Temporary handbooks set up
33 Faculty handbook completed
34 Administrators determined
35 Instructors selected
36 Faculty appeals body established
37 Dean of Students personnel selected
38 Teaching load established
39 Faculty outside employment policy established
40 Contracts and grants policy established
41 Instructor application forms completed
42 Business manager appointed
43 Copyright and patent policies established
44 Procedures for faculty resignations established
45 Teacher qualifications determined
46 Faculty counseling services established
47 Secretarial and clerical staff selected
48 Leave policies established
49 Procedures for faculty appointments established
50 Procedures for faculty dismissals established
51 Nonprofessional personnel appointed
52 Group life insurance established
53 Faculty fringe benefits determined
54 Hospital, medical, and disability income insurance established

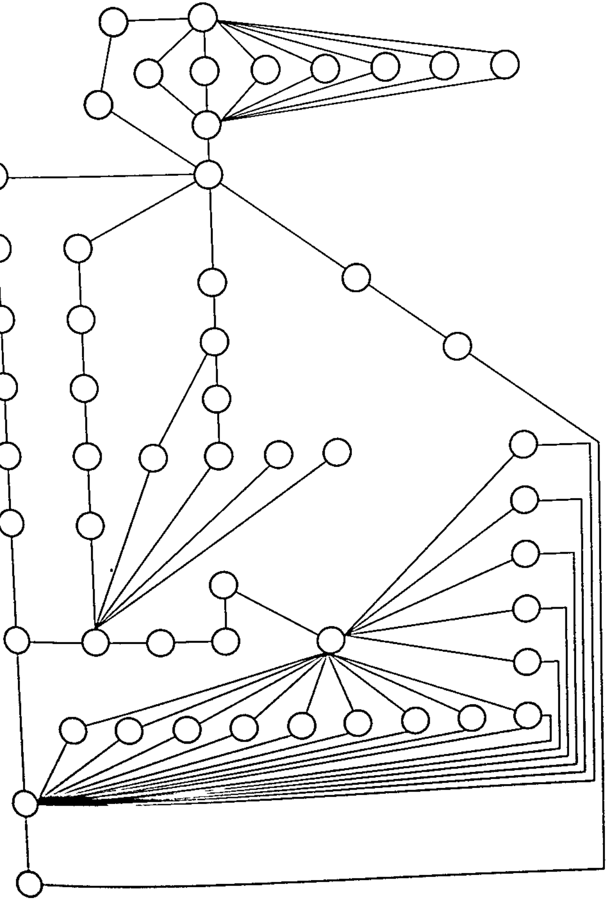


Figure 6.37. *Personnel.*

Buildings

1 Equipment delivered and checked
2 Preliminary drawings completed
3 Final payment
4 Education Specifics determined
5 Inspection team selected
6 Contract awarded
7 Temporary quarters set up
8 Equipment bids let
9 Architect hired
10 Building and other costs estimated
11 Construction begun
12 Criteria sited
13 Working drawings completed
14 Equipment operation approved
15 Competence of bidders checked
16 Community survey completed
17 Legal aspects checked
18 Buildings occupied
19 Site purchased
20 Construction contract prepared
21 Dean hired
22 Business manager appointed
23 Facilities specifications completed
24 Building data compared
25 Construction completed
26 President hired
27 Building specification completed
28 Buildings dedicated
29 Sites tested against criteria
30 Advertised for bids
31 Educational philosophy established
32 Preliminary drawings approved by state
33 Consultant hired
34 Architect s schematic approved
35 Architect and board accept bid
36 Equipment installed
37 Final drawings specifications guarantees instructions delivered
38 Advisory board for site determined
39 Buildings approved
40 Building committee appointed
41 Three legal bodies approved

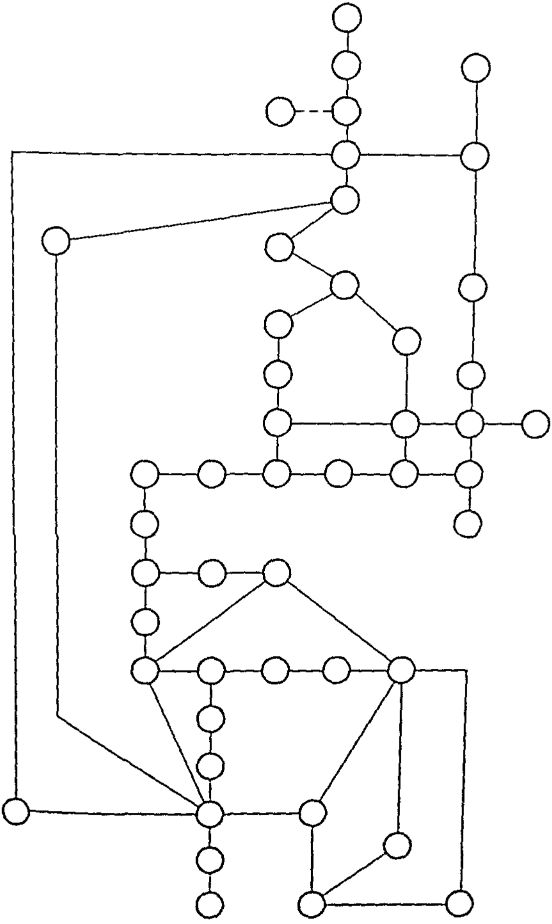


Figure 6.38. *Buildings.*

42 Performance bond posted
43 Architect s schematic drawings completed
44 Equipment bids accepted
45 Site selected
46 Preliminary drawings approved by board
47 Equipment needs determined

Instructional Program

1 Number and type of degrees determined
   (1) Process for students to follow in changing major
   (2) Retention
   (3) Transfer requirement
   (4) Dismissal
   (5) Quality points
   (6) Class attendance
   (7) Semester hours and quality points
   (8) Requirements for majors
   (9) Honor s work
   (10) Readmission
   (11) Auditors
   (12) Academic load
   (13) Residence requirements
   (14) Dean s list
   (15) Course examinations
   (16) Academic probation
   (17) Grading practices
   (18) Schedule change
   (19) Physical education requirements
   (20) Special students
   (21) Classification of students
   (22) Withdrawal
2 Book list determined
3 Levels integrated
4 Adult needs established
5 Summer catalog completed
6 Date of application determined
7 Courses for first year determined
8 Curriculum approved by board
9 Process for changing curriculum established
10 Required tests determined
11 Instructional areas recommended to board

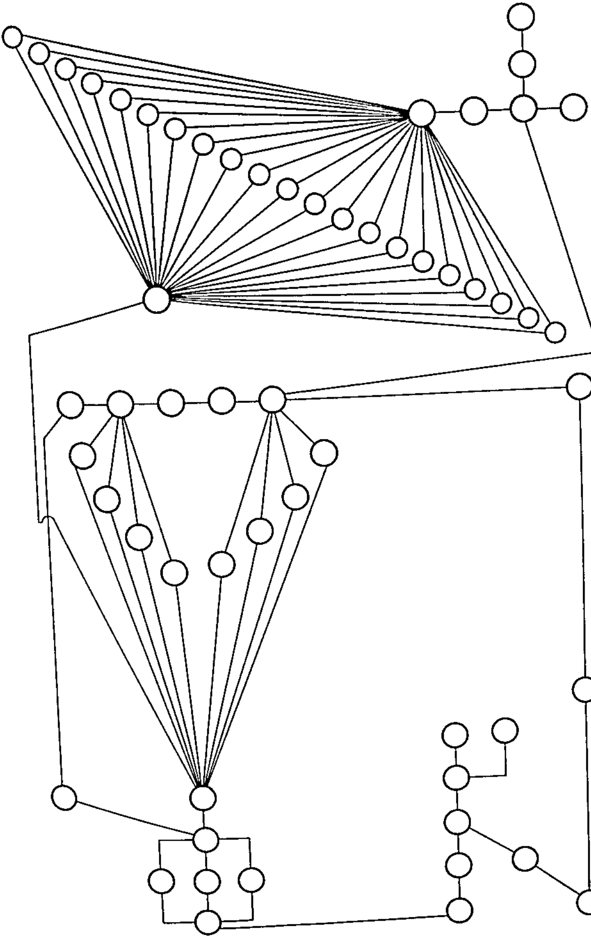


Figure 6.39. Instructional program.

12 Long range enrollment determined
13 Regular catalog completed
14 Admission requirements established
15 Statement of curriculum objectives completed
16 Community needs determined
17 Duplication with senior institutions established
18 Temporary catalog for early students completed
19 Class size determined
20 School calendar set up
21 Curriculum evaluation procedures determined
22 Consultant hired
23 Number of sections per course determined
24 Board approval
25 Student needs determined
26 Exemption examinations set up
27 School degree requirements determined
28 General education requirements determined
29 Curriculum approved by State Department
30 Instructional areas recommended to president
31 First year enrollment determined
32 Curriculum standards for accreditation established
33 Course description completed
34 Classes opened
35 Audio-visual aids determined
36 Placement tests given
37 Dean hired

Student Affairs

1 Counselor hired
(1) Student government
(2) Intramurals
(3) Clubs and organizations
(4) Job placement
(5) Food service
(6) Athletics
(7) Student publications
(8) Financial Aid
(9) Attendance
(10) Instructional supplies
(11) Social activities
(12) Honors Day

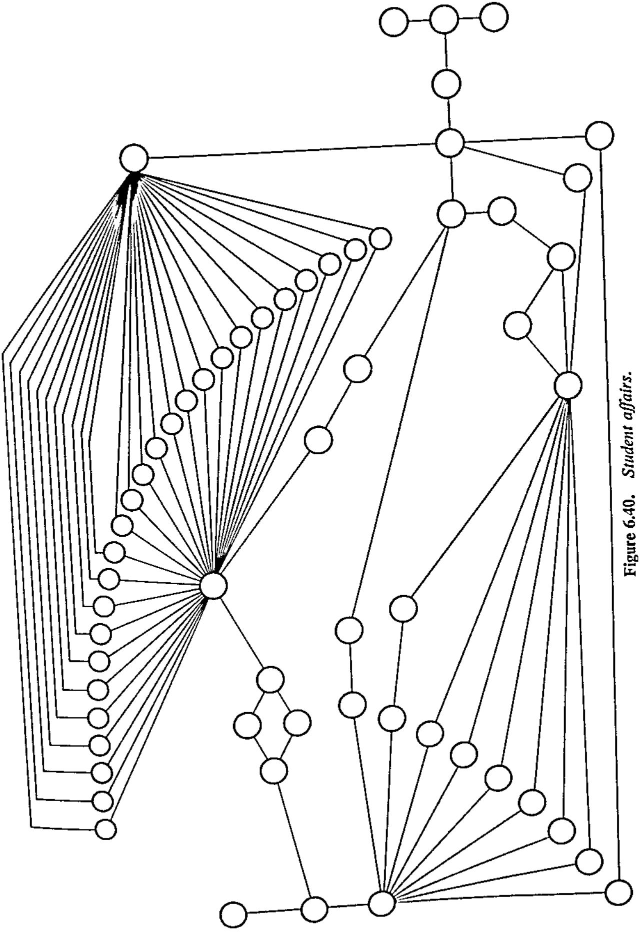


Figure 6.40. *Student affairs.*

(13) Parking policy
(14) Student work load policy
(15) Housing
(16) Health
(17) Suspension and withdrawals
(18) Grading policy
(19) Library
(20) Assemblies
(21) Activities calendar and notices
(22) Transfers
(23) Graduation policy
(24) Student center
(25) Fees
(26) Discipline

2 Temporary catalog set up
3 Student handbook completed
4 Health services determined
5 Instructors appointed
6 Student affairs committee set up
7 Admissions requirements set
8 Pre admission counseling completed
9 SPS budget completed
10 Dean of students selected
11 Tests and answer sheets received
12 Applications processed
13 Student personnel services organization chart established
14 Bussing policy established
15 Regular catalog completed
16 Placement tests ordered
17 Institutional research office established
18 Faculty orientation to counseling procedures completed
19 Plans for computer assisted records initiated
20 Pre-admissions counseling program set up
21 Acceptance letters mailed
22 Dean of students appointed
23 Pre-admissions testing program set up
24 Classes opened
25 Temporary catalogs distributed
26 Secretary hired
27 Financial aid established
28 High schools visited
29 Admission forms prepared

30 Orientation begun
31 Public relations brochure completed
32 Student records and grade reports prepared
33 Registration completed

Note: Appreciation is extended to Mrs Cynthia Ma for assistance in preparing the figures in this chapter

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CHAPTER 7

Systems Cost Analysis

Introduction

The primary function of management is to develop the optimal allocation of available resources, the assumption being that there is a definite limitation of the resources available This is usually referred to in terms of scarcity of resources The problem of allocating resources involves consideration of the selection of a set of alternatives from among various available alternatives $(a_1, a_2, a_3, \quad a_n)$ In order to make a selection from among various available alternatives, it is necessary to assign cost-utility ratios to the various alternatives One maximizes the cost utility ratio MAX c_i/u_i Cost utility ratios have implications about the nature of cost and the nature of utility One does not ordinarily think of cost in the context of strictly dollar costs Rather cost implies the trade off of alternative investments for the dollar investment

The utility function is associated with the long range value or gain involved in the particular course of action This implies total optimization insofar as the utility function is concerned rather than suboptimization In other words, quite frequently certain courses of action or decisions made about specific programs within the educational system might, if taken alone, furnish a

compelling reason why one should allocate resources to them However, when the total system is taken into account it may be better to not optimize a particular program but make it subordinate to the gain of the entire system It is readily evident that the procedure used in doing a cost analysis is one segment of the total systems analysis

There are several by-products associated with doing a systems cost analysis One of the primary by-products is that it forces management to make a clear statement of the objectives for the organization So far as education is concerned this has been one of the most difficult aspects of the entire systems analysis Traditionally, educators have associated the end-product with achievement of children This, of course, is not necessarily the end-product but rather somewhat of a quality control of the end-product

There appears to be a growing sensitivity to the fact that a primary purpose of education rests in the development of human resources Therefore, any evaluation of education must be concerned primarily with how the educational system is developing human resources Again referring to the problem of testing, it is necessary to monitor the general quality of the educational system, but that is not the final objective The important thing is to stipulate the nature of the objectives, not to make decisions about what objectives are Once the objectives are specifically stipulated, it is within the analyst's capability to design the criteria and set up suitable alternatives Once the criteria and alternatives are established, it is a relatively straightforward thing to evaluate the alternatives and select the best from the several available alternatives

In brief, systems cost analysis is concerned primarily with the evaluation of various alternative courses of action There are three primary concepts associated with systems cost analysis One, is a matter of costing per se. It has been pointed out that this involves not merely a dollar type of costing but rather the total cost in terms of various alternatives to which one might put the resources which are available The second major concept deals with the matter of utility, and this is essentially the matter of assigning numbers to the value or return to the corporation of various alternative courses of action Finally, this chapter will be concerned with the problem of budgeting because the allocation of resources is concerned basically with the problem of allocating financial resources Although the resources of any educational system are financial, physical, and human, the development of the physical and human resources is dependent primarily upon the fiscal resources available Therefore, the balance of this chapter will be concerned with the concept of cost utility and budgeting

Cost Factors

Costing procedures have evolved over a considerable period of time The current analytical procedures, however, are closely associated with the development of quantitative approaches to administrative decision-making Some of the present areas where costing functions have been widely applied include:

National security
Economic planning
Defense Department management
Military decision making
Weapons selection
Resource allocations
Space systems
Nuclear systems
Space-flight ground-support systems
Advanced-weapon systems
Defense procurement
Electronics industry
National objectives
Weapons-acquisition processes
Management information systems
Military R & D systems
Logistics systems
Manpower-requirement systems
Data-processing systems
Manpower support systems
Educational data-processing systems
Educational-personnel systems
Student-record systems
Educational fiscal-management systems
Educational-building systems

The majority of the applications of costing follow the general pattern of the conventional systems study However, the costing functions per se are associated primarily with the criteria established for evaluating alternatives Almost invariably systems analyses culminate in costing alternative courses of actions These costing procedures very seldom occur in isolation They are usually associated with utility function numbers In the field of education the lack of ability to attach utility function numbers to various operational

activities has created a major problem. It is also worth mentioning that cost information alone does not force a decision. However, information of such nature is extremely useful to the decisionmaker because it furnishes quantitative hard data.

A system cost analysis does not refer exclusively to dollar cost. The term implies a broader connotation that the economist usually associates with price theory. That is, the cost of the activity is not the absolute dollar value but is interpreted to mean the alternative activities that must be given up in order that a given activity can be implemented. Referring again to the economist's notion in price theory, assume a manufacturer is to build refrigerators and decides to commit $100,000 to the project. The actual cost consideration for the project is not $100,000 but is the amount which would have been spent on an alternative product plus the return on that alternative product. It would appear worthwhile to use a comparable approach for allocating fiscal resources to educational projects. One, therefore, must consider both the cost and the payoff or utility of these projects.

The typical cost effectiveness curve is *S* shaped and follows the logistics pattern. This *S* shaped curve is bilaterally symetrical. As the cost increases, the effectiveness increases as a function of cost. The original half of the curve is accelerating but midway in the curve at the point of inflection, the curve enters the point of deceleration. The continuing cost has smaller and smaller marginal return insofar as effectiveness is concerned.

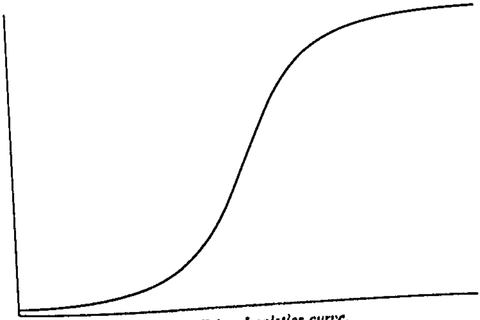

Figure 7.1. *Logistics curve.*

One of the better illustrations of cost effectiveness is a mathematical model for cost effectiveness analysis[1] Hatry and Cotten were concerned with the general problem of selected manpower programs The primary objective of the project was to eliminate unemployment of a certain hardcore group within a specified jurisdiction A couple of alternative courses of action were proposed One dealt with the encouragement of mobility of unemployed persons by affording grants to encourage them to move to a new community The alternative approach was a training program that offered a course of instruction to enhance the performance of the unemployed The assumption underlying the training program was that if the person had salable skills, there would be a spot whereby he could find a job

This type of project lends itself well to cost effectiveness procedures because of available numbers that can be assigned to the number of unemployed, the period of training, and the precise number of persons that have gone into active jobs This project illustrates also the combination of cost and utility It is apparent that many of the educational programs being conducted in the public schools lend themselves quite well to this type of cost analysis There are reasonably hard numbers available dealing with the cost to society if the educational system does not retain a student long enough to make him a productive member of society There are also hard data available to furnish information to the educational decision maker regarding the relative payoff for those programs which deal with such things as special education, driver training, math, science, and the arts The emphasis again on all costing functions is not one of efficiency of dollar invested The costing factor can be given any definition desired by the school system

Cornelson estimates the cost associated with training under the Manpower Development and Training Act of 1962 and also gives the relative return for those persons who have undergone training under this act

> Of those completing their training, (2 out of 10 dropped out) 70 per cent or 7,111 persons found jobs immediately, most of the other 30 per cent were placed later Our measure of the monetary returns on the investment is based on the earnings of those who went to work immediately, our measure of the training costs is based on all 13,000 trainees At the time the 7,111 went to work the average hourly wage for the occupations in which they were trained was $2 01 In 24 weeks, then, they earned $13 7 million, in that brief time, through the taxes they paid and the goods and

[1] Harry P Hatry and John F Cotton *Program Planning for State, County, City* Washington D C George Washington University, 1967, pp 45–58

services they bought, they returned to the economy an amount somewhat higher than the $13 3 million it cost to train the entire group of 13,000 The returns can be expressed in many other ways For example In federal income tax alone—assuming $220 of the 1964 rate for an average annual income of $4,180 in a family of four—the trainee will repay the cost of his training in 5 years In only 1 year of employment the average trainee can be expected to earn $4,180, or $3,135 more than it cost to train him An investment of $13 3 million in training is expected to result in gross earnings of over $148 million in 5 years Every dollar spent in training the group should return $2 24 a year in gross earnings Not only did these persons earn enough to make the public's investment worthwhile, but they were able to remove themselves from relief rolls What they would otherwise have cost in unemployment compensation and public assistance is another item we must include in our balance sheet as we attempt to put a dollar measure on the worth of vocational training [2]

The argument might be made that it is impossible to attach cost functions to educational programs Since education is not a profit operation, any attempt to quantify the different educational programs is impossible When the National Institutes of Health were asked to do a cost analysis on the health programs, the first response was that it was impossible to put a dollar sign on a human life However, when the National Institutes of Health were forced into that type of decision making, Table 7 1 from *Business Week* was a partial result This table represents a five-year program for the fiscal years 1968 to 1972 The costing done by the National Institutes of Health was primarily based upon economic benefits for saving lives The economic benefits to the country might not be an unrealistic benefit if the programs are being funded from national funds Table 7 1 gives a breakdown of the cost in millions of dollars for each program, the potential savings in lives, the cost per life, the total savings in millions of dollars and the total savings per one dollar spent One can assume that other factors enter into the decision regarding the amount of money to be put into any particular program However, it is obvious from Table 7 1 that the information given when costing analysis is done adds considerable weight to the decision-making process Referring to Table 7 1, it would be easy to make a decision regarding the amount of money put into encouraging the use of seat belts versus the "don't drink and drive" campaign If one had an additional $100,000 to

[2] Leroy A Cornelson "The Economics of Training the Unemployed" *School Life*, XLVII (October, 1964), p 18

Table 7.1. What's A Life Worth to the Budget Bureau? (A Five-Year Program for Fiscal Years 1968–72)

	Cost (in millions of dollars)	Potential savings in lives	Cost per life	Total savings (in millions)*	Savings per $1 spent
Highway Accident Campaign					
Encourage the use of seat belts	$2 0	22,930	$87	$2,728	$1,351
Promote chest and shoulder belts	6	5,811	103	681	1,117
Educate accident-prone pedestrians	1 1	1,650	666	153	144
Encourage motorcyclists to use helmets, eye shields	7 4	2,398	3,336	413	55
"Don't drink and drive" campaign	28 5	5,340	5,824	613	21
Medical screening program for driver licensing	6 1	442	13,801	23	3
Disease Campaigns					
Cancer					
Cervical-uterine cancer (screening program)	118 1	34,200	3,470	1,071	9
Breast cancer (screening program)	22 4	2,396	7,663	101	4
Head and neck cancer (detection research)	7 8	268	29,100	9	1
Lung cancer (anti-smoking education program)	47 0	7,000	6,400	268	5
Arthritis					
Treatment centers, clinics, professional education	35 0	—	—	1,489	42

Table 7.1. (*Continued*)

	Cost (in millions of dollars)	Potential savings in lives	Cost per life	Total savings (in millions)*	Savings per $1 spent
Disease Campaigns *(continued)*					
Syphilis					
Expand blood screening efforts	179 3	11,590	22,252	2,993	16
Tuberculosis					
Step up research and control	130 0	5,700	22,807	573	4

Source "Putting a Dollar Sign on Life," *Business Week* (January 21, 1967), p 87 Reprinted by special permission Copyright © 1967 by McGraw Hill

* Direct and indirect savings through earning power of individuals Data Health, Education & Welfare Dept

put into the NIH program other things being equal, the payoff would be substantially greater by putting the $100,000 into a campaign to encourage the use of seatbelts There are, of course, cautions to be exercised in interpreting Table 7 1 One does not know precisely how many people will be convinced that they should actually use their seatbelts if a seatbelt campaign is embarked upon The figures are thought-provoking, and the difference in savings between a medical screening program for driver licensing and a medical-screening program for cervical-uterine cancer are different by a factor of three Therefore, it would appear that the return to the country would be greater if the money were spent on a screening program for cervical-uterine cancer rather than a screening program for driver licensing

The *Business Week* article reports on an illustrative comparison of two HEW plans presented for cervical-uterine cancer One cost, $155 million was estimated to save 44,084 lives at a cost of $3,520 per person over a five-year period Another plan would cost $118 1 million and save 34,200 persons at cost of $3,470 each On the other hand, if money were put into a colon-rectum cancer campaign it would cost $7 3 million over five years to save about 170 persons This would be a cost of $42,941 per person It would appear that the obvious place for HEW to place the majority of funds would be in cervical cancer Again, this would not imply that no funds would be placed in the colon-rectum cancer program, but the majority of the funds would be

put in the cervical-cancer fund Another obvious area which HEW should finance is in the area of arthritis to salvage people who would otherwise be unemployed A return of approximately $42 for every dollar spent could be expected NIH elected to put $35 million into this program with a potential saving of $1,489 million It can be safely assumed that those persons would more than repay the arthritis costs in taxes that they would pay to the government from earnings This same type of costing should be applied to educational programs that have as one of their major objectives gainful employment at the appropriate level for all citizens These data are readily available from work statistics for persons salvaged from the drop out group Those persons taken from welfare rolls are prevented from re-entering the welfare rolls Such an in depth analysis furnishes compelling evidence for cost utility studies

There is still a considerable reluctance on the part of professional educators to accept the concept of using cost as a major decision-making variable This is usually due to the lack of understanding of the implications of the term, costing It is difficult to conceive of a school system being operated without major consideration being given to costing of various programs However, the apparent coldness of cost-utility effectiveness as a measure for decision making creates a negative reaction in many people In addition to the emotional reactions to cost-utility effectiveness procedures and their use in educational decision making, there are other aspects of cost-utility that limit its usefulness One of these variables is the more or less restricted scope of most cost analysis studies In general, it is impossible to incorporate all of the cost variables that might have some influence upon the system By using a fragment of the total system, there is always the risk of optimizing a subsystem at the expense of the total system An experienced analyst, however, will be aware of the pitfalls of suboptimization and will control for that variable in his cost analysis

One example of suboptimization is a special program that has considerable publicity appeal Frequently resources are allocated to the particular program that furnishes the system with a great deal of publicity, at the expense of the efficiency of the total system A second area which restricts the effectiveness of cost analysis is that of lack of baseline data Most cost studies are based on a single system and therefore lack an adequate criterion with which to measure the effectiveness of costing It is extremely helpful, however, for a school system to have baseline data even if those baseline data are based upon national norms

A third area that limits cost analysis is that of measurement Much data

in the areas of education, business, and economics are not easily quantifiable and consequently do not lend themselves nicely for analytical purposes Therefore, much of the data must be treated in semiqualitative form The use of quantitative approaches for analysis when semiqualitative data are used poses difficulties It is possible, however, to furnish some quantification to semiqualitative data This is done by using ranking procedures and forcing relative positions among several alternative activities For example, assume that a set of alternatives, a_1, a_2, a_3, a_4, exists All four alternatives are qualitative in nature, such as a superintendent wishing to keep his job, a good public relations image, an innovative school program, and a good educational system First assign numerical values to each alternative, a_1, a_2, a_3, a_4, based upon subjective judgment as to the relative rank of each and the approximate distance between ranks Next, assume one alternative is more important than the other three Set up the inequality, a_1 is greater than a_2 plus a_3 plus a_4 ($a_1 > a_2 + a_3 + a_4$) Compare the number assigned If a_1 is not greater that the sum of a_2 plus a_3 plus a_4, adjust a_1 such that the inequality will hold Next take a_2 and set up the inequality a_2 is greater than a_3 plus a_4 ($a_2 > a + {}_3 a_4$) If the inequality is not true, again adjust a_2 to make it true It should be noted that this might change the value for a_1 If so, make that change Next, set up the inequality a_3 is greater than a_4 ($a_3 > a_4$) As before, if this inequality is not true, change the number for a_3 such that it will be true and make the adjustments in a_2 and a_1 In order to give a normalized scale, take the four numbers now assigned to a_1, a_2, a_3, and a_4, sum these numbers, then divide a_1 by the sum, a_2 by the sum, a_3 by the sum, and a_4 by the sum The new values for a_1, a_2, a_3, and a_4 should now be equal to one These are now normalized scores and complete the conversion of the prior qualitative data into what are now quantitative data This last example illustrates how one can treat data which appear to be strictly nonquantitative as fully quantitative data

A word of caution is in order Not all educational decisions lend themselves to costing type procedures However, there is a large block of activities that do lend themselves well to costing activities For those activities costing procedures should be used

Utility Theory

The preceding pages have been concerned primarily with the costing function It has been pointed out that cost per se does not mean merely dollar

amounts The economist's point of view of cost is the concern That is, what alternative courses of action could have been initiated if the dollars spent for activity *A* had been spent for some other kinds of activities There is in addition to this more broad view of the concept of cost an additional very important aspect of cost analysis This other aspect is that of utility Utility refers to the assumed or real value derived to an individual or an organization from a specific activity or set of activities There is a formal axiomatic base for utility theory However, utility (as used in cost-utility-effectiveness measures) takes cognizance of the behavioral or psychological aspects of the problem in addition to the strictly quantitative and mathematical aspects Solomon points out the basic problems associated with the use of cost-utility analysis,

> A typical decision situation involves three things, (1) an individual faced with the necessity of making a choice, (2) a certain set of alternatives among which the individual must choose, and (3) the system of subjective preferences or values by which the individual ranks the alternatives, choosing that one which stands highest according to his values [3]

This mathematical approach is used primarily to help the decision maker Cost-utility measures do not force a decision, they merely present the official decision maker with additional information whereby he can make a better decision He always has the option to refuse to use the information presented to him

A few basic concepts should be mentioned before the formal basis for utility is given In any utility system, there is an assumption that the alternatives can be ranked This is referred to as the "ordinal assumption" Implicit in the ordinal assumption is the concept of preference The assumption is made that the individual can make a choice or express his preference among the several alternatives and rank those alternatives according to his preferences A second fact to be considered in dealing with utilities is that one is dealing essentially with probabilities or risks The same type of deterministic mathematics utilized in physics or in a physical experiment, for example, usually does not apply in the area of utility These are probabilistic functions They are subject to random variations in addition to individual whims that in many cases make the probabilities highly subjective As is well known, however, probability theory has evolved to the point where one can be secure

[3] Herbert Solomon, editor *Mathematical Thinking in the Measurement of Behavior* New York The Free Press of Glencoe, 1960, p 158

in decision making as long as one knows the limits of error The typical administrator does not insist upon being 100 per cent right He is willing to be wrong 5 or 10 per cent of the time, particularly if he can see in advance the likelihood that he will be wrong

Finally, inherent in the area of utility is the concept of expectations The mathematics of expectations is based essentially on that of probability and statistics Since the key to the concept of utility is that of value received or payoff or return to the individual or the firm, the mathematics of expectations is highly relevant to utility theory Calculations of expectations will be illustrated in some of the following pages A study of utilities is closely associated with the economic returns from education and although a great deal of effort has been expended in this regard, less than a fourth of the states are actively engaged in cost-utility analysis This small number is surprising because education is a major business and has been responsible for much of the economic growth of the nation In 1957 the labor force in the United States represented an educational capital of 535 billion dollars In 1964–1965 the United States spent approximately 39 billion dollars in education in comparison with the gross private domestic investment in 1964 of 93 billion dollars Estimates have been made that the average quality of labor between 1929 and 1957 was raised 29 6 per cent by education The financial returns from education has been evaluated in terms of lifetime earnings Figure 7 2 illustrates this point

Utility theory combines several of the concepts of quantitative approaches and the psychological aspects of decision making For example, assume that the dollar is a basic monetary unit and buys the same amount of merchandise regardless of who makes a purchase Further assume that flipping an unbiased coin results in a probability of 5 that the coin rests heads up and a probability of 5 that it rests tails up

Would you accept a bet under the following conditions you received five dollars if tails comes up, you pay one dollar if heads comes up? Since the odds are very much in your favor you probably would accept the bet

Now assume that you had just used your last dollar to pay off the mortgage on your $30,000 home Would you accept a bet with the odds as above? That is, would you be willing to give up your house if heads came up provided you received $150,000 if tails came up? You might accept this latter bet but you would no doubt, give much more consideration, before accepting, than you would in the former bet The apparent change in value of the money involved the concept of utility

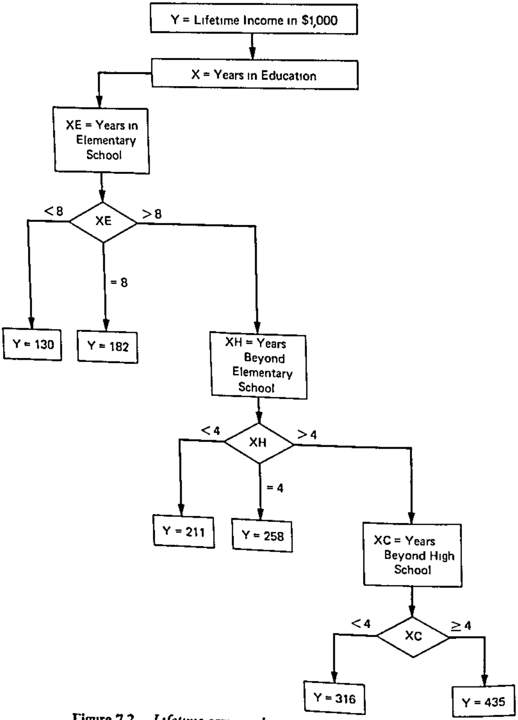

Figure 7.2. *Lifetime earnings by years of education*

Definition there is a utility function u on the set of prospects to the set of numbers, That is, to each prospect P, there corresponds a number $u(P)$ which is called the utility of the prospect P This function has the following properties, called the utility function properties

UTILITY FUNCTION PROPERTY 1
$U(P_1) > U(P_2)$ if and only if the individual prefers P_1 to P_2

UTILITY FUNCTION PROPERTY 2
If P is the prospect where, with probability p, the individual faces P_1 and with probability $1 - p$ he faces P_2, then $U(P) = pu(P_1) + (1 - p)u(P_2^2)$ [4]

A clear understanding of the term "prospect" is necessary *The American College Dictionary* defines prospect as "an apparent probability of advancement, success, profit, etc " Both the dictionary definition and technical sense of the term imply a return of value for taking a given action There is also an implication of relativity That is, a prospect has a potential return in relation to another prospect Selection of the prospect with the greatest probability of return involves the process of decision making under utility rules

Property No 1 is an order axiom If prospect one is preferred to prospect two, then the utility of the former is greater than the utility of the latter Also if prospect one is less preferered than prospect two, then the utility of the former will be less than the utility of the latter If prospects one and two are equally preferred, then their utilities will be equal

Property No 2 is an additive axiom It states that the return in a given circumstance of products is a function of the sum of the relative probabilities and their associated utilities

In general, if P_1 has an associated probability p_1, P_2 has an associated probability p_2, and P_n has an associated probability p_n then

$$U(P) = p_1 u(P_1) + p_2 u(P_2) + \quad + p_n u(P_n)$$

Property No 2 is highly relevant for long range planning It furnishes the likelihood of long range utility given that certain prospects are likely to occur

Assumptions

There are four assumptions associated with the definition of utility given above The four assumptions are presented and discussed below To complete

[4] Herman Chernoff and Lincoln E Moses *Elementary Decision Theory* New York John Wiley & Sons, 1959, pp 80–81

the definition given earlier, one should substitute for the three dots and rephrase the definition as follows *Given the four assumptions which follow,* there is a utility function u on a set of prospects to the set of numbers That is to each prospect there corresponds a number $u(P)$, which is called the utility of the prospect P

"Assumption 1 With sufficient calculation an individual faced with two prospects P_1 and P_2 will be able to decide whether he prefers prospect P_1 to P_2, whether he likes each equally well or whether he prefers P_2 to P_1 "[5]

Given Assumption 1, three decision-making conditions and utility states are possible

$$U(P_1) > U(P_2)$$

$$U(P_1) = U(P_2)$$

$$U(P_1) < U(P_2)$$

The relationship between P_1 and P_2 is always such that the utility of P_1 is greater than, equal to, or less than P_2

If a decision maker selects the greater utility then (assuming that the utility is known) the utility function logic will provide a maximum return for that decision

"Assumption 2 If P_1 is regarded at least as well as P_2, and P_2 at least as well as P_3, then P_1 is regarded at least as well as P_3 "[6]

Assumption 2 is a restatement of the order axiom which states if

$$a \geq b$$

and

$$b \geq c$$

then

$$a \geq c$$

Using the same logic, if

$$u(P_1) \geq u(P_2)$$

[5] *Ibid*, p 82.
[6] *Ibid*

and

$$u(P_2) \geq u(P_3)$$

then

$$u(P_1) \geq u(P_3).$$

"Assumption 3. If P_1 is preferred to P_2, which is preferred to P_3 then there is a mixture of P_1 and P_3 which is preferred to P_2, and there is a mixture of P_1 and P_3 over which P_2 is preferred."[7]

Assumption 3 calls attention to the possible variable nature of the individual prospect.

CASE 1:

Assume

$$P_1 = 100$$
$$P_2 = 60$$
$$P_3 = -30$$

then

$$P_1 + P_3 > P_2$$

or

$$100 + (-30) > 60.$$

CASE 2:

Assume

$$P_1 = 100$$
$$P_2 = 60$$
$$P_3 = -50$$

[7] *Ibid.*

then

$$P_1 + P_3 < P_2$$

or

$$100 + (-50) < 60$$

"Assumption 4 Suppose the individual prefers P_1 to P_2 and P_3 is another prospect Then we assume that the individual will prefer a mixture of P_1 and P_3 to the same mixture of P_2 and P_3 "[8]

Assumption 4 presupposes fixed preferences for P_1, P_2, and P_3 If the prospects are fixed then, of course the following relationships hold

$$P_1 > P_2$$

Adding a constant to both sides gives

$$P_1 + P_3 > P_2 + P_3$$

The four assumptions given above furnish the ground rules for calculating utilities

Budgeting

The budget is the most central, organizational document It furnishes a blueprint for the entire corporation

The budget is a detailed log of all transactions It represents a complete fiscal picture of income and expenditures It is the roadmap which dictates the direction of the system over the budgeted time period It can be either a flexible dynamic instrument or a static restrictive instrument It can furnish the general guidelines for the activities of the system allowing flexibility for the system to adjust to changing conditions and to adapt to opportunities It can also be the restricting influence which locks operations into a predesigned plan allowing little flexibility for change during the budgetary time period During the past decade new views regarding the budgetary process have come into

[8] *Ibid*

existence The trend is to view the budget as a dynamic flexible instrument that maps out the corporate plans but encourages flexibility in a dynamic changing society There is also a tendency away from the one-year budgetary time period to more long range planning of the budgetary process Because of the emphasis upon flexibility long-range planning is possible That is if the long-range planning is considered to be a general blueprint rather than a rigidly structured plan, long range planning becomes both feasible and desirable Much of the changing attitude toward the budgetary process has come about through the influence of the work in systems analysis Quantitative scientific approaches used by systems analysts lend themselves well to the budgetary process Most budgets, whether local school systems, municipal governments, state governments, or federal government are reasonably continuous documents Only under exceptional circumstances are there quantum jumps in the budgetary amounts This is true regardless of the source of the funds Also as the budget becomes a document reflecting programs more than expenditures the allocation of resources becomes more of a systematic process rather than an arbitrary process If one projects the needs for programs including the analysis of past experiences, then the allocation of resources to those programs becomes more compelling If one bases the allocation of resources only along traditional lines of expenditures according to fixed budgetary items, then the allocation of resources is more arbitrary and based upon individual judgment rather than upon systematic analysis of needs The shifting views of the budgeting process were dramatized by the President of the United States in 1965 when he announced a program approach to budgeting for the federal government At that time the main agencies of the United States government were directed to implement these new views on budgeting The President stated

> "This program is designed to achieve three major objectives, it will help us find new ways to do jobs faster, to do jobs better, and to do jobs less expensively It will ensure much sounder judgment through more accurate information, pinpointing those things that we ought to do more, spotlighting those that we ought to do less It will make our decision making process as up to date, I think, as our space exploring programs
>
> This new system will identify our national goals with precision and will do it on a continuing basis It will enable us to fill the need of all the American people with a minimum amount of waste [9]

[9] Lyndon B Johnson, Speech 1965 Unpublished directive given by President Lyndon B Johnson, on August 25, 1965, to all federal department heads and agencies

The summary statement by the President in 1965 emphasized the role of the budget in the decision-making process This is in contrast to the traditional budgetary procedures whereby funds were allocated according to item expenditures There are also political implications for viewing the budget as a mission oriented document that assists in the decision-making process It should be much easier to sell the budget if one is selling programs rather than selling expenditures Priorities become much more clear to those who are in a position to approve or disapprove the budget if they have a clear concept of the purpose for which the funds are to be expended The budget document in this regard becomes a graphic illustration or a picture of the benefits to be derived from the expenditure of funds requested Unfortunately this political aspect of the budgetary process has been minimized too frequently in educational corporations

The objectives of budgeting cover five major areas, analyzing, planning, controlling, monitoring, and evaluating for effectiveness The budget document furnishes the primary source for analyzing various functions of the system It furnishes a detailed breakdown regarding the allocation of resources, hence, it lends itself well to the procedures of cost budgeting In any type of effective analysis of an organizational function, the primary consideration must be that of allocating fiscal resources The worth of any program in the last analysis is reflected in the expenditures that the system makes to that program Expenditures are considered here as the total effort, both financial and human, as well as the possible return from alternative courses of action if the resources had been allocated to some other activity

Planning

The budget is essentially a planning document Of course, the planning time varies according to the budgetary procedure used However, the primary purpose of the budget is to furnish a blueprint for the system activities over a given period of time In this sense it is a detailed planning document that stipulates how the resources of the corporation will be allocated among the various programs implemented by the corporation As the changing concept of the budget is emphasized, planning has begun to take on a new proportion It is not unusual at present for educational corporations to do their planning over a five-to-ten year period This is in contrast to the traditional one-year planning period In so far as the budget document is a flexible blueprint for planning, it is the ideal instrument for the educational corporation to use in its long range planning The heart of any planning involves commitments regarding the allocation of resources on the part of the system Since the budget

is the final commitment of such allocation of resources, it is the primary planning document

Fiscal Control

The budget is the traditional document that furnishes the administrative decision-makers with overall control of the corporation It is a running record of all of the activities of an official nature that require formal commitment of system resources The tendency to look at the budget as a flexible document has changed somewhat the concept of fiscal control It is no longer used as the life or death control over the personnel and operations of corporations Rather it's considered as a document that reflects the system's commitment to the programs The budget reflects the priorities of the various programs and the consequent relative support of each program Since the current budget is closely associated with cost-utility analysis, the transfer of funds within the budget becomes a more systematic decision-making procedure Any funds that are reallocated within the budget must be considered in the light of the trade-off and the effects that they have on the balance of the budget and the total system operations

Monitoring

One of the most valuable functions of the budget is the continuous monitoring of the overall operations of the system The automated systems of fiscal management have furnished a new dimension in the overall monitoring of the system's affairs, that is, an almost instantaneous control of the flow of documents which represent financial expenditures within the system One can monitor on a daily basis the various administrative operations of the corporation A good illustration is the current automation of the purchasing department, where the document is completely automated from the time of initiation of the request for expenditures through the entire purchasing process until the time that checks are written Included in this procedure are the necessary adjustments to the budget This type of automated procedure allows for continuous monitoring of the fiscal status by the chief administrator

Evaluating Effectiveness

Because the newer concepts of the budget are closely allied to systems analysis and cost utility analysis, the budget furnishes the primary source for evaluation of the effectiveness of different programs If the budget is program

oriented, it is easy to relate the specific expenditures to particular programs In the more traditional budget document, this is difficult to do because the items are listed according to expenditure rather than according to support of specific programs It is clear, then, that the budget has become a much more responsive instrument to the overall operations of the system It represents much more adequately a specific program that the system has underway Therefore, it is a much more effective blueprint of the true operations because it lends itself so well to the procedures for measuring effectiveness

Programming—An Accounting Document

The traditional budget has been primarily concerned with accounting problems That is, it is concerned with the appropriate allocation of resources according to item expenditure categories The typical educational budget has a breakout for such expenditures as administration, capital outlay, instruction, transportation, and special services It has traditionally been a static document prepared in advance of a current fiscal year The items within the budget categories have remained relatively constant Table 7 2 furnishes a budget breakdown according to major categories by percentage and per pupil The figures in Table 7 2 are based upon national norms Table 7 3 furnishes a budget breakout of a typical school system of approximately 50,000 students This table is concerned with the budget as an accounting document No attempt has been made to associate either revenues or expenditures with specific programs Present day budgeting has been reviewed in terms of the departure of the traditional breakdown of salaries, capital expenditures, grants, and maintenance operations The present-day budgeting procedures are not

Table 7.2. Budget Breakdown

Source	Percentage	Per pupil ($)
Instruction	75 38	327 79
Plant Operation	9 26	40 27
Auxiliary Services	4 97	21 61
Administration	3 73	16 21
Fixed Charges	3 63	15 79
Plant Maintenance	3 03	13 18
TOTAL	100 00	434 85

Table 7.3. Typical Budget for 50,000 Students

Instruction	$16,389,500
Plant Operation	2,013,500
Auxiliary Services	1,080,500
Administration	810,500
Fixed Charges	789,500
Plant Maintenance	659,000

dramatic departures from the classical accounting procedures Such accounting procedures are still required in most states for budgetary reporting There is no reason why a modern budget cannot be a combination of the classical accounting and the mission oriented budget The new NEA Handbook II on commercial accounting for local school systems will be a combination of classical accounting procedures coupled with some mission orientation There are additional advantages to retaining at least the essence of the classical accounting procedures for purposes of comparing the local system-budget breakout with national norms For example, the budget given in Table 7 3 might be compared with national norms The design of a budget in terms of the administrative milestones in the preparation of the budget has been given in the design of an information system A complete breakdown has included the approximate dates when certain budgetary items should be completed during the year

The Budget—A Program Document

As indicated earlier the budget as a program document allocates resources according to missions in a system According to Anshen this is in contrast to budget preparation in terms of item expenditures

> The Main Advantage claimed for the program budget is that it promises to do this more effectively and more efficiently by (1) providing a framework for more clearly defining alternatives among which choices must be made and (2) creating an information system that will assist in measuring costs in relation to accomplishments [10]

[10] Melvin Anshen, "The Federal Budget as an Instrument for Management and Analysis," in *Program Budgeting*, David Novick, editor, Cambridge, Mass Harvard University Press, 1965, p 18

Anshen's reference reiterates the decision-making role of a program budget Many of the budgetary objectives for a program budget are similar to the traditional accounting type budget

Again according to Anshen there are seven primary objectives in any budget

> First, the budget design should facilitate meaningful measurements of the total money costs of accomplishing defined objectives Second, the budget structure should facilitate comparison of alternative ways to accomplish a given objective Third, the budget presentation should clearly identify future cost implications inherent in interim financial commitments Fourth, the budget design should facilitate comparison of cost unputs and achievement outputs when related segments of a single program are administered by different management units Fifth, the budget design should delineate the objectives of discrete spending commitments in such terms that significant cost effectiveness (cost utility) analysis can be carried out Sixth, the budget design should make it possible to aggregate very related expenditures wherever they occur in the government's sprawling administrative structure Seven, a budget that effectively meets the foregoing criteria should go far toward serving another important need, that of generating economic data on federal inputs to national economy by meaningful activity segments [11]

Anshen's objectives stress the importance of combining the budget with cost-utility analysis Here again the relationship between modern day budgeting and systems analysis is apparent

Fisher has further emphasized the relationship between systems analysis in the budget referring to cost-utility analysis

> Cost utility analysis, as envisioned here, may be distinguished by the following major characteristics 1 A fundamental characteristic is the systematic examination and comparison of alternative courses of action that might be taken to achieve specified objectives for some future time period 2 Critical examination of alternatives typically involves numerous considerations, but the two main ones are assessment of the costs (in the sense of economic resource costs) and the utility (the benefits or gains) pertaining to each of the alternatives being compared to attain the stipu-

[11] *Ibid*, 10–11 pp

lated objectives 3 The time contacts is the future (often the distant future—five, ten, or more years) 4 Because of the extended time horizon, the environment is one of uncertainty (very often great uncertainty) 5 Usually the context in which the analysis takes place is broad (often very broad) and the environment very complex, with numerous interactions between the key variables in the problem 6 While quantitative methods of analysis should be used as much as possible, because of items 4 and 5 above, purely quantitative work must often be heavily supplemented by qualitative analysis 7 Usually the focus is on research and development and/or investment type decision problems, although operational decisions are sometimes encountered 8 Timeliness is important [12]

Fisher's general outline of cost utility, which is closely allied to the budgetary process, contains the essential ingredients of a comprehensive systems analysis That is, a careful delineation of objectives is made, the appropriate set of alternatives is established, a systematic evaluation of alternatives is made, and finally the selection is made from one or more of the various alternatives According to Novick

> The new program-budget procedure has two primary aims first, to permit analysis of total force structures for all of the services in terms of common missions or national objectives, second, to protect the resources impact (or financial requirements) of the proposed force structure over an extended period of years [13]

Hatry and Cotton have listed the immediate value for program budgeting for states and localities The following seven points summarize their view

(1) Long range fiscal planning becomes routine All government programs have to be viewed in a perspective that considers not only the expenditures in the immediate budget period but for the years ahead
(2) Plans and programs are reviewed continuously Under the system progress on each program will have to be reviewed each year, and the program revised, when new, previously unknown factors come into

[12] Gene H Fisher, "The Role of Cost Utility Analysis in Program Budgeting" in *Program Budgeting*, David Novick, editor Cambridge, Mass Harvard University Press, 1965, p 66–67

[13] David Novick, "The Department of Defense," in *Program Budgeting*, David Novick, editor Cambridge, Mass Harvard University Press 1965, p 87

play, or when previous judgments have to be corrected The periodic review helps to ascertain whether existing and proposed programs are the most effective ways of accomplishing a particular government mission The most effective way is to be determined in terms of budgetary costs, the extent to which ample or scarce resources (for instance, highly skilled labor) are to be utilized, and whether a program has a positive or negative effect with respect not only to the primary but also to the secondary goals

(3) Governmental activities are classified in terms of programs and their purposes Budgeting by programs rather than by administrative units, by budgeted positions, and by object expenditures has long been advocated It permits a better understanding of the role of individual activities in meeting governmental objectives

(4) Interagency coordination of programs is strengthened The system requires that each agency of the government engage periodically in meaningful self examination both in terms of the specific function of the agency, and of the relation of this function to the activities of other agencies of the government The latter requires interagency discussion and clarification, even prior to review in any office for program coordination

(5) Intergovernmental planning is improved Federal aid programs will be viewed in the context of the jurisdictions' own program plans The system will strengthen the federal effort toward improving budgeting and decision making by a counterpart effort in the state and local governments where the major portion of civilian public services are provided

(6) A program evaluation cycle of program formulation, progress reporting, and program revision is established Planning will be linked to budget decisions and program evaluation to planning The budget process becomes a more meaningful tool of government

(7) Each program is to be evaluated in terms of national goals This requires not only consideration of the appropriate functions of the various levels of government but also the relationship of government to private activities in the same field, activities which may either support these goals, or be in conflict with them [14]

As a comparative budget with that given of a 50,000 student school system, Table 7 4 shows the budget in program form in a study submitted by a Subcommittee on Intergovernmental Relations

[14] Hatry, *op cit*, p 7

Table 7.4. Illustrative PPB System Government Program Structure

Summary

I Personal safety
II Health (physical and mental well-being)
III Intellectual development and personal enrichment
IV Satisfactory home and community environment
V Economic satisfaction and satisfactory work opportunities for the individual
VI Satisfactory leisure time opportunities
VII Transportation-communication-location
VIII General administration support

Notes

1 This program structure is for illustrative purposes only Its underlying framework is the identification of the needs of the individual citizen

2 It is not a complete program structure More detail is used in some areas than others, many categories have not been subcategorized sufficiently Each individual government jurisdiction needs to specify the primary governmental objectives of its activities and based upon this formulate its own specific program structure The lower level program categories particularly are difficult to structure without reference to the specific governmental jurisdiction and its problems

3 It is highly desirable to have a statement of objectives, in as specific terms as possible, for each element of the program structure

4 Such activities as planning, research, and experimentation should be included with the program structure category to which they apply If applicable to a whole program area (i e , I through VIII above) it might be included under an " unassignable" category as shown below

5 Categories shown in brackets are those which seem to fall readily into more than one location of the program structure The brackets indicate the "secondary" location for these categories to avoid double counting when grand totals are prepared

6 In many cases, it will be appropriate to include subcategories which distinguish particular " target groups " For example, consideration should be given to identification of certain programs by age, race, income level, geographical location type of disability, etc One illustration is shown under category IV A For the most part, however, this program structure does not identify target groups

7 The lowest level categories, not illustrated here, should identify the specific programs or activities

I Personal safety (protection from personal harm and property loss)
A Law enforcement (i e , crime prevention and control) [1]
1 Crime prevention

[1] In addition, programs for juveniles should probably be distinguished from programs for adults Sub-categories for major types of crime might also be appropriate

Table 7.4. (continued)

Summary

- 2 Crime investigation
- 3 Judging and assignment of punishment
- 4 Punishment and safekeeping of criminals
- 5 Rehabilitation of criminals
  - (*a*) Probation
  - (*b*) Parole
  - (*c*) Rehabilitation while confined

B Traffic safety
- 1 Control
- 2 Judging and punishment
- 3 Accident prevention

C Fire prevention and firefighting
- 1 Prevention
- 2 Fighting

D Safety from animals

E Protection from and control of the natural and manmade disasters
- 1 Civil defense
- 2 Flood prevention and control
- 3 Miscellaneous emergencies/disaster control
  - (*a*) National Guard
  - (*b*) Emergency rescue squads
  - (*c*) Other

F Prevention of food and drug hazards, nonmotor vehicle accidents and occupational hazards

G Unassignable research and planning, personal safety

H Unassignable support, personal safety

II Health (physical and mental well being) [2]

A Physical health
- 1 Preventive medical services
  - (*a*) Chronic diseases
  - (*b*) Communicable diseases
  - (*c*) Dental disorders
  - (*d*) Other
- 2 Treatment and rehabilitation
  - (*a*) Communicable diseases
  - (*b*) Dental disorders
  - (*c*) General
  - (*d*) Other

[2] Subcategories distinguishing programs for various age groups and for specific diseases would be appropriate Medical assistance welfare programs should probably be included here as well as under V A (and placed in brackets in one place or the other)

Table 7.4. (*continued*)

Summary
B Mental health
1 Mental retardation
(*a*) Prevention
(*b*) Treatment and rehabilitation
2 Mental illness
(*a*) Prevention
(*b*) Treatment and rehabilitation
C Drug and alcohol addiction prevention and control
1 Drug addicition
(*a*) Prevention
(*b*) Treatment and rehabilitation
2 Alcohol addiction
(*a*) Prevention
(*b*) Treatment and rehabilitation
[D Environmental health, included under IV C through G]
E Other
F Unassignable research and planning health
G Unassignable support, health
III Intellectual development and personal enrichment [3]
A Preschool education
B Primary education
1 Education for special groups
(*a*)Handicapped
(*b*) Culturally deprived
(1) Tutorial assistance
(2) Family orientation
(3) Mass media
2 General education
C Secondary education
D Higher education
1 Junior colleges
2 Liberal arts colleges
3 Universities
4 Specialized professional schools other than 5
[5 Medical and dental schools training functions, included under II]

[3] In many cases, neither State, county, nor city governments will control the bulk of the programs and expenditure for education However, these are of such importance, and inter relate with all other program areas, that it may be advisable to retain this complete category The jurisdictions would focus upon those areas which they control and those which seem to be neglected and for which government encouragement can be given

Table 7.4. (*continued*)

Summary
E Adult education
1 General
[2 Adult vocational education, included under V B]
[F Public libraries, included under VI C 2]
[G Museums and historical sites, included under VI C 1]
[H Vocational education other than III E 2, included under V B]
I Other
J Unassignable research and planning, intellectual development and personal enrichment
K Unassignable support, intellectual development and personal enrichment
IV Satisfactory home and community environment (creation of a livable and pleasant environment for the individual)
A Provision of satisfactory homes for dependent persons
1 For children
2 For youth
3 For the aged
4 Other dependent persons
B Provision of satisfactory homes for others
1 Upgrading existing housing
2 Satisfactory supply of homes for low-income persons
3 Information and counseling to home dwellers
4 Enforcement of housing standards
5 Land use regulation
C Maintenance of a satisfactory water supply
1 Water supply
2 Water sanitation
3 Storm drainage (this category might also be included under I E 2)
D Solid waste collection and disposal
1 Garbage
2 Refuse
E Maintenance of satisfactory air environment (including air pollution control)
F Pest control
G Noise abatement
H Local beautification
I Intracommunity relations
J Homemaking aid and information

Table 7.4. (*continued*)

Summary
K Other
L Unassignable research and planning, satisfactory home and community environment
M Unassignable support, satisfactory home and community environment
V Economic satisfaction and satisfactory work opportunities for the individual
A Financial assistance to the needy (other than for homes, which is included in IV B and C)
1 Aid to the blind
2 Aid to the disabled
3 Aid to the aged
4 Aid to families with dependent children
5 Aid to the unemployed (other than above)
6 Programs to reduce the cost of living
B Increased job opportunity
1 Job training
2 Employment services and counseling
3 Job creation
4 Combinations of 1, 2, and 3
5 Equal employment opportunity
6 Self employment assistance
C Protection of the individual as an employee
D Aid to the individual as a businessman, including general economic development
1 Support for individual industries
2 General community promotion
E Protection of the individual as a consumer of goods and services (other than food and drug hazards contained in II A 1 (*c*))
F Judicial activities for protection of consumers and businessmen, alike
G Other
H Unassignable research and planning, economic satisfaction and satisfactory work opportunities for the individual
I Unassignable support, economic satisfaction and satisfactory work opportunities for the individual
VI Satisfactory leisure time opportunities
A Provision of outdoor recreational opportunities
1 Parks and open space
2 Athletics and playgrounds
3 Zoo
4 Other

Table 7.4. (*continued*)

Summary
B Provision of indoor recreational opportunities
1 Recreation centers
2 Other
C Cultural activities
1 Museums and historical sites
2 Public libraries
3 Theaters
4 Music activities
5 Other
D Leisure-time activities specifically for senior citizens
E Other
F Unassignable research and planning, leisure-time opportunities
G Unassignable support, leisure-time opportunities
VII Transportation-communication-location[4]
A Motor vehicle transport
1 Highways
2 Streets
[3 Traffic safety, included under I B]
4 Parking
B Urban transit system
C Pedestrian
D Water transport
E Air transport
F Location programs
G Communications substitutes for transportation
H Unassignable research and planning, transportation-communication-location
I Unassignable support, transportation-communication-location

[4] The inclusion of the terms "communication" and "location" are to emphasize the need to consider the broader spatial relationships involved Thus, the relative location of homes, jobs, and businesses, etc , will have a significant effect upon the transportation and communication systems needed Such other categories as IV B 5 (land use regulation) will interact with this program area

Transportation activities predominantly concerned with one of the preceding program packages should be assigned to them For example, park road activities would be included under IV A Note Transportation-communication-location is not really an end in itself but rather supports other objectives such as employment (commuter service), economic progress, recreation, etc However, because of its importance in most communities and the need to consider transportation systems in an integrated manner, identification as a separate major program area seems justified When evaluating alternatives, the fundamental purposes of transportation should be recognized

Table 7.4. (continued)

Summary
VIII General administration and support.[5]
A. General government management
B Financial
1 Expenditures
2 Revenues
3 General
C Unassignable purchasing and property management
D Personnel services for the government
E Unassignable EDP
F Legislative
G Legal
H Elections
I Other[15]

[5] This category contains activities that cannot reasonably be assigned to the other major program areas For example, the following should be assigned, to the extent possible, against the specific programs generating the need for these expenses Research and planning, employment benefit expenses, maintenance of buildings and equipment, data processing costs, special purpose engineering, and associated capital costs

There is an essential feature about a program budget that extends beyond the mere listing of budgetary items This feature involves the primary objective of systems analysis which is cost-utility analysis It is generally agreed that the main contribution of the program budget over the accounting budget lies in the decision-making process The new budgeting procedures are not without their limitations

> As the total system of planning programmed budgeting develops school systems will have to conform to all of the criteria, guidelines, directives and evaluative processes of each federal program from which they get money with the result that their freedom to choose will be increasingly curtailed[16]

The Department of Health, Education, and Welfare is now in the process of having a hard look at the program budgeting process Exton has listed the six activities and purposes

[15] U S Subcommittee on Intergovernmental Relations, *Criteria for Evaluation in Planning State and Local Programs*, 80–976, 90th Congress, 1st Session, 1967, pp 37–42

[16] Elaine Exton, "Federal Program Budgeting is a Step Toward Centralized Education Planning," *American School Board Journal*, (November, 1966), p 43

1 Human Investment Programs To increase the income earning capacity and improve the functioning of individuals and families (Examples Education programs aimed at raising the future income of children from poor families and providing higher educational opportunities for needy college students Includes such things as adult basic education, ESEA Title I, vocational education and the National Teacher Corps)

2 Income and Benefit Programs The social insurance and assistance programs designed to provide individuals and families with supplements to their current incomes (Examples Cash payment programs such as aid to families with dependent children and programs providing goods and/or services such as Medicare)

3 Institutional Development and Community Improvement Programs (Examples Educational assistance programs for supplementing the resources of educational institutions and for increasing the supply of trained professional, educational, scientific and technical personnel engaged in health, education and welfare activities Includes strengthening instruction in science, math and other critical subjects, school assistance in federal affected areas, assistance to state education agencies [Title V of ESEA], innovation assistance [Title III of ESEA], higher education facilities construction, teacher training grants, and student aid)

4 Research Programs for gaining a fuller understanding of physical and social processes and human behavior, and for investigating new educational methods and new techniques for transmitting knowledge and information (Examples Cooperative Research Act as amended by Title IV of P L 89–10)

5 International Programs To support the government's effort to assist the health, education, and welfare programs of other nations

6 General Support Costs of administration and management which cannot be directly allocated to the "mission programs" and of providing "for the flow of information to official bodies and the public "

These broad HEW mission categories usually are divided into program sub categories which, in turn, consist of program elements, the lowest classification under which specific program activities are reported [17]

Exton has also indicated some cautions in the political sphere "While conceding that strengthening the information environment for legislators would aid them in reaching sound decisions on education proposals, still others contend the danger lies in whether staff the legislators employ will

[17] Elaine Exton, ' Here s How HED Department Applies Planning Programming Budgeting System *School Board Journal*, (December, 1966), pp 5–6

have the requisite technical and research skills in education or be an idea-group which reflects some special interest "[18]

The importance of the discussions underway about program budgeting require that school boards begin to look into all implications of the new budgeting system (See Exton, page 43, March 1967, School Board Journal) In an unpublished dissertation from the University of Wisconsin in 1966, James Everett Jernberg reports on program budgeting the influence, affects, and implications of reform Although not definitive in its own right, the Jernberg dissertation points out the political hazards in any type of budgetary procedure

In his dissertation at Yale in 1966, Allen Schick reported on program budgeting in the states, the pathology of administrative reform Schick is critical of the program budgeting approach and refers to the wide publicity given to the program budgeting concept, but it has not lived up to expectations He reports combinations of the program budgeting approach with the object of expenditure form of classification Schick also points out the likelihood that program budgeting has not been widely adapted because there has been little attempt to adopt the cost benefit analysis and performance measurements that are the inherent part of the programmed budgeting procedure Reviewing the literature on budgeting leads one to the conclusion that at this time an eclectic approach is likely to be the most successful of the budgeting procedures, that is, an objective expenditure form of budgeting combined with a mission oriented budget

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[18] Elaine Exton, "State Legislators Urged to Install Planning Programming Budgeting System," *School Board Journal*, (February, 1967), p 15

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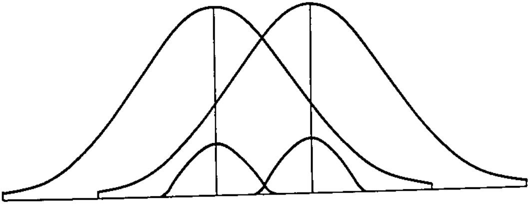
PART **FOUR**

SYSTEMS TECHNOLOGY



CHAPTER 8

Simulation

Models and Simulation

The concepts of models and simulation are closely related One cannot conduct a simulation without first building a model of the system A model is not necessarily an exact replica of a system, but must contain the essential aspects of the system By omitting the trivial details and concentrating on the essential features, the simulation becomes an efficient and effective processor of the functions of the system The following steps furnish a guideline for model construction

- Step 1 Define the problem in specific terms such that the problem lends itself to quantitative labeling
- Step 2 Construct a flow chart such that all steps in the model are clearly detailed
- Step 3 Collect preliminary data that are adequate for purposes of plotting
- Step 4 Graph the data
- Step 5 Determine the problem form of the equation from the graph
- Step 6 Test the derived equation for accuracy and predictability

Two common types of models are mathematical and analog A mathematical model is an idealized representation of a concept, object or situation The functional notation of the mathematician implies that if y is a function of x, then y is determined if x is given

Consider the case where $y = x$ as in Table 8 1 and Figure 8 1

Table 8.1.
$y = x$

x	y
0	0
1	1
2	2
n	n

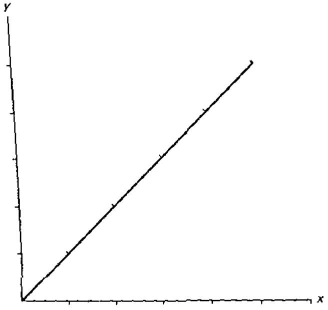


Figure 8 1 *Graph of* $y = x$

This table and figure denote that for each integer increase in x, there is a corresponding increase in y That is y is a function of x, $y = f(x)$

The equation for the linear function in Table 8 1 and Figure 8 1 is given by $y = ax + b$ where a is the rate of increase of y in respect to x, and b is the intercept (in this case zero)

Various curves have been constructed to model physical systems For example the parabola is a model of the trajectory of a cannon ball as in Figure 8 2

Another common curve is the half-life decay curve, which has had wide applications in radioactive isotopes and biological sciences. This curve is a negative exponential $y = Ae^{-at}$ and is illustrated in Figure 8.3.

The essence of each of the models lies in the fact that if x is known, y can be predicted. An interesting aspect of the model is that any value of x can be assigned. Hence the behavior of y can be studied under any condition of x.

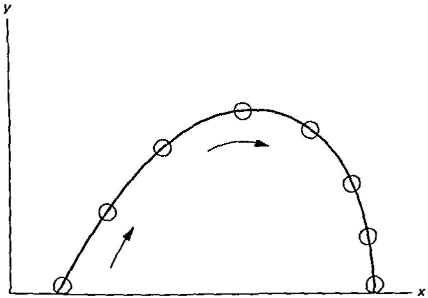


Figure 8.2. $y = a + bx + cx^2$.

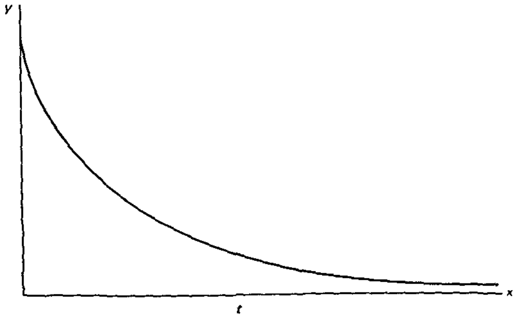


Figure 8.3. $y = Ae^{-at}$.

These models involve the concept of independent and dependent variable This concept is the essence of simulation One manipulates the independent variable and observes the dependent variable

Analog models are frequently constructed for purposes of studying complex systems The analog model varies in complexity depending upon the complexity of the system and the ingenuity of the model creator Two common analog models are presented here, the electrical and mechanical The electrical model is shown in Figure 8 4

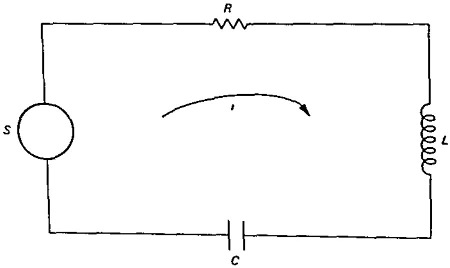


Figure 8 4 *Electrical model*

S = source
R = resistor
L = inductor
C = capacitor
i = current

S is an active energy source
R is a passive element which converts energy to heat
L is a passive element which stores electromagnetic energy
C is a passive element which stores electrical potential energy
i is the flow of current

A current i flows through the system from the energy source S and is influenced by the resistors, inductors, and capacitors If S, R, L, and C are analogs to functional subsystems, one can study the total system by studying, through manipulation, the effects of appropriate variables

The electrical system in Figure 8.4 can be put in equation form as follows:

$$S = Ri + L\frac{di}{dt} + \frac{1}{C}\int i\, td.$$

Differentiating and rearranging terms result in the differential equation which follows:

$$\frac{dS}{dt} = L\frac{d^2i}{dt^2} + R\frac{di}{dt} + \frac{i}{C}.$$

The change in S in respect to time is a function of L, R, and $1/C$. By substituting different values for each of these variables L, R, and $1/C$, one can simulate the total electrical system under any desirable conditions.

A mechanical model is illustrated in Figure 8.5, where,

m = mass
k = spring constant lb/ft
c = damping factor lb/sec/ft
x = displacement.

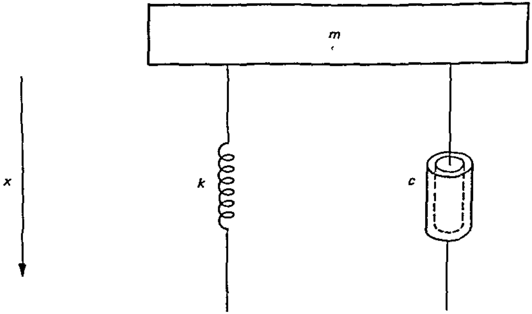


Figure 8.5. *Mechanical model.*

The differential equation which defines the mechanical system above follows

$$F_{(t)} = m \frac{d^2x}{dt^2} + c \frac{dx}{dt} + kx$$

There are certain analogies between the electrical and mechanical systems given below

Electrical	Mechanical
L	m
$1/C$	k
R	c
S	F
i	x

In each of the models discussed the potential for simulation is clear Behavior of the total system is observed following manipulations on subsystem valuables such as L, C, R, m, k, and c

Definition

The definition of *simulate* given by *Webster's Seventh New Collegiate Dictionary* is "to give the appearance or the effect of" *The American College Dictionary* definintion of *simulate* is "to make a pretense of or to assume or have the appearance of"

Malcolm defines a system simulation project as

> One which depicts the workings of a large scale system of men, machines, material and information operating over a period of time in a simulated environment representative of the actual real world con ditions A simulation project generally utilizes an electronic computer and may operate in "real" time or in compressed time where the simulated system may be operated for several years in but a few hours of computer time [1]

[1] Donald G Malcolm, ' The Use of Simulation in Management Analysis A Survey,' in *Scientific Decision Making in Business*, Abe Shuchman, editor New York Holt, Rinehart and Winston 1963, p 417

Robinson speaks of simulation in reference to business

> In many cases we would like to know in advance something about the probable behavior of a business operation or competitive system before we actually start it We cannot usually arrange to have an experiment conducted using an entire business operation, simply because it would take too long, be too costly or be contrary to company policy, and so forth About the only way that we can hope to predict the consequences of our actions before committing ourselves, is through intuitive business judgment, scientific study, or possibly sheer speculation Probably the best approach is to apply a useful scientific method to support experienced management judgment This is where we come to the possibility of simulation—particularly if we are dealing with a changing or dynamic situation with some complexity [2]

According to Chorafas,

> Simulation involves the construction of a working mathematical or physical model presenting similarity of properties or relationships with the natural or technological system under study In this manner we can preoperate a system without actually having a physical device to work with, and we can predecide on the optimization of its characteristics In most cases, simulation studies, to be properly done, require the making of new models able to fit, with the required precision, a specific situation *It is like developing a special kind of medicine to suit the needs of an* individual patient [3]

The common element running through the various cited definitions refers to a model that is a representation of the real situation The original applications of simulation were directed toward military activities and industrial and business functions More recently simulation techniques have been applied to the field of education The range of application of simulation to education includes studies in teacher preparation

Cruickshank has contrasted the traditional techniques of observation and student teaching with newer simulation techniques that are being tested to meet the criterion of realism They also provide a setting wherein the trainee

[2] Patrick J Robinson, "Cases in Simulation A Research Aid As a Management 'Demonstration Piece,'" in *Scientific Decision Making in Business*, Abe Shuchman, editor New York Holt, Rinehart and Winston, 1963, pp 425–426

[3] Dimitris N Chorafas *Systems and Simulation* New York Academic Press, 1965, p 15

or teacher-in-service may practice a wider range of teaching behavior without fear of censure or failure In the simulation study by Cruichshank, each participant assumes the role of a teacher just employed by a school system in a make-believe community The system and school are introduced by a film strip, faculty handbook of rules and regulations, curriculum handbook, audio-visual catalog and cumulative record cards for thirty-one children

The game begins by exposing the participant to thirty incidents representing problems identified by teachers in service After each incident, the participant notes reactions on a written form that identifies the problem, and then decisions are made Group discussions follow each of the reactions Participants report the simulation experience stimulating and highly motivating Simulation allows the participant an opportunity for unfettered practice of principles he has learned in education courses The participants become acquainted with school records, regulations, and children in meaningful ways With increasing shortage of available space for participants and student teachers in the schools, simulation plays an important role [4]

The advent of the computer has given considerable impetus to simulation Scientific war games and business games have been developed by military and industrial operations research groups These games are divided into three types computer simulations, digital man-machine games, and continuous variable man-machine games

Computer simulations or completely automated games are always rigid, usually stochastic, and generally very detailed They are not limited by decision-making speed of human beings Digital man-machine games employ digital computers for bookkeeping, computing, and data transmission People are used for decision-making, electronic analogue computers, for computation Human decisions are introduced continuously rather than periodically as the game proceeds [5]

Charles Mayer reported a study dealing with interviewing cost and survey research This study was concerned with the task of developing a simulation model of the interviewing process and demonstrating how such a model can help the manager of a field force in choosing among alternate plans of sample design and field procedures An analysis of over 3,000 report forms submitted by field interviewers on past studies permitted formulation of certain

[4] Donald R Cruickshank, "*Simulation-New Direction* in Teacher Preparation," *Phi Delta Kappan*, (September, 1966), pp 23–24

[5] J O Harrison, Jr *Computer-Aided Information Systems for Gaming* AD 623091, (September, 1964) ASTIA Document Washington, D C Armed Services Technical Information Agency

hypotheses concerning the nature of the interviewing environment These hypotheses were used to define the structure of the simulation model From these report forms the actual value for the input parameters were derived A 709 IBM digital computer was selected as the simulation vehicle Cost curves were generated for a large metropolitan and other urban and rural areas The model defined the shape of the curves and also supplied reasons for the slopes Alternative strategies were tested Mayer concluded that it was possible to construct a simulation model of the field interviewing process that would behave in approximately the same way as the real system [6]

The Sperry and Hutchinson Company are developing statistical and mathematical forecasting procedures that furnish management with a data-display command center Eventually the current data displays will aid management in making decisions on locating warehouses and forecasting changes in redemption rates more accurately [7]

Various training simulators have been developed into quite sophisticated trainers Wright and Terrett describe applications of hybrid computers in training crews for manned space vehicles and submarine duties Such simulators have been used extensively by Air Force and civilian pilot training [8] These combined engineering system simulators offer some promise in various aspects of the professional area of education

Cogswell reports a project underway at Systems Development Corporation that is making use of techniques relatively new to education research New solutions for implementing instructional media are found through analysis of school organization simulation Four major steps involved in the project include (a) survey and selection of high schools, (b) systems analysis of five high schools selected for study, (c) construction of a computer simulation vehicle that will provide the capability of building detailed dynamic models of schools and of hypothetical changes in the schools, and (d) simulation study of the five high schools with the simulation vehicle Future plans for the simulation vehicle involve (a) processing samples of students through any kind of school, (b) providing information regarding the changes that may occur in students and resources through time, (c) providing the capability of getting a report on student and resource changes at variable time intervals,

[6] Charles S Mayer, "Interviewing Costs in Survey Research—A Computer Simulation Study," *Michigan Business Reports*, No 46, (1964), p 94

[7] Alan Drattell, "A Near-Mis Puts Customers On Line," *Business Automation*, (April, 1966) 54-57

[8] P A R Wright and D S Terrett, "A Hybrid Computer As a Training Simulator," *Radio and Electronic Engineer* (October 28, 1964), pp 261-264

(d) permitting simulation of resource depletion to show the defects on students where resources are not available, (e) providing a record of any student's history through the school, (f) yielding detailed and summarized reports on each activity, and (g) showing the student load or different activities at different time periods [9]

A seminar by Railway Systems and Management Association of Chicago reveals that simulation is being used by railroads Logical methods of operation are being programmed into a computer along with "what is" attitudes Electronic simulation is aiding railroads by breaking yard bottlenecks, improving utilization of freight cars and motor power, planning capital outlays for new equipment, planning operations changes and consolidations under merger, and improving present operations [10]

Simulation of demographic data has been noted in a paper presented at the American Sociological Association meeting, 1965 Berry reports on several models dealing with application of mathematical models to geography Demography lends itself relatively well to the quantitative approach for models of simulation [11]

Hagerstrand has also reported on the mathematical model dealing with demographic variables and computer simulation Hagerstrand runs through several levels of complexity simulating social and demographic data [12]

Simulation Language

Most simulation exercises are conducted on computers The time and cost of writing a simulation program is considerable Fortunately, however, programs have been written for popular computer equipment The following table from Tocher summarizes several major simulation programs [13]

Programs listed in Table 8 2 are available from European and United States sources Modifications of the available programs satisfy most require-

[9] John F Cogswell, 'Systems Analysis and Computer Simulation in the Implementation of Media," *Audiovisual Instruction* (May, 1965), pp 384–386

[10] Nancy Ford, ' What If Simulation," *Modern Railroads* (May, 1966), pp 94–102

[11] Brian J L Berry, paper presented at American Sociological Association Meeting, 1965, Chicago, Ill

[12] Torsten Hagerstrand, "A Monte Carlo Approach to Diffusion," *European Journal of Sociology*, VI (1965), pp 43–66

[13] K D Tocher, "Review of Simulation Languages,' *Operational Research Quarterly*, XVI (June, 1965), p 191

Table 8.2. Simulation Programs

Language	*Basic language*	Dominant *type of entities*	*Principal authors*	*Machine implemented for*
GPSS	None	Material	Gordon	IBM 7090
SIMPAC	SCAT (assembly)	Material	Lackner	IBM 7090
SIMSCRIPT	FORTRAN	Material	Markowitz	IBM 7090
SIMULA	ALGOL	Material and machines	Nygaard and Dahl	Univac 1107
CSL	FORTRAN	Machines	Buxton, Laski	IBM 7090 IBM 1620 *IBM 1410*
			Clementson	Honeywell 400/1400 200/2200
ESP	ALGOL	Machines	Williams	Elliott 503
GSP*	None	Machines	Tocher	Ferranti Pegasus Elliott 503
MONTECODE	AUTOCODE	Machines	Buxton and Head	Ferranti Pegasus
SIMON	ALGOL	Machines	Hills	Elliott 503 and an 8,000 word 803

* GSP II, *in preparation GSP I is now obsolete*

ments Tocher has elaborated upon the table by furnishing reasonable detailed descriptions of the major simulation programs

> In order to make comparison of the various languages, it has been necessary to describe them in common terms, but this is not necessarily how their authors view them, and it is now necessary to give a brief account of each language phrased, as far as possible, in the spirit of the originator.
>
> Lackner has stressed that the language structure must match the theory of systems being used
>
> GPSS This programming system can best be described as a computerized version of the work study engineer's flow chart. The system consists of a number of different types of blocks representing different kinds of interaction of the system with a transaction The blocks of each type require a specification (particular to their type) including the possible successor blocks (and a rule to choose between them)

A work-study flow diagram is drawn from these blocks, specifications of each block are recorded, and, when presented to the computer, constitute the program There are no formal statements as in normal languages, but these are implied by the data supplied about the blocks and the implied behaviour of the blocks

This attractive idea is worked out very fully, but to give the flexibility required for the study of general systems the number of block types and their specifications becomes quite complex Although some attempt is made to make the specification of simple types be implied by omission of data, the impression remains that there is still an amount of redundancy

Monitoring and changing program facilities are rather weak and certainly involve re-assembly There is presumably no formal compiling step as the system acts on the data concerning each block interpretively

SIMPAC It is emphasized in the literature that this system is not a general model, but consists of a package of facilities useful to assembly simulation models

The central idea of this system is that each process applied to transactions is in three parts, receiving them in a set of input queues, processing them, delivering them to a set of output queues Systems are conceived of as a system of interlocking queues and each process is connected to a pair of sets of queues by rules associated with the processes

Thus, SIMPAC has a similar motivation to GPSS to represent the system as a flow chart, but uses only two kinds of object, queues and processes The flexibility has now to be obtained by a wider variety of properties of these two elements, and the impression is gained that the system must take a lot of learning, this feeling is enhanced by the reference manuals which are written in computer specialists' jargon

SIMSCRIPT, by contrast, has a beautifully lucid manual, full of ex amples The language is in the normal form of a series of statements grouped together as an event The computer is made to obey these statements at simulated times specified earlier by what are called event notices

In contrast to the other American systems, it is truly general, leaving the user to create entities out of the formal apparatus provided, with complete freedom to define their properties as required It is the material-based equivalent of CSL

SIMULA is a highly abstract language, which centres round two ideas The first is the duality in event networks between machines and material The language is designed to allow formulation in either form The second concept is that the specification of a process involves statements that will be obeyed at different times (e g the beginning and the end of the process) The description is all gathered together in one piece of

program and the computer is responsible for separating them into parts obeyed at different times While this may be of advantage to a user completely ignorant of programming, it is an added complexity for the ordinary programmer and must certainly complicate the compiling process

The description of the language available concentrates on these almost philosophical aspects of the problem, and dismisses the practical problems of sampling, etc , in a few lines A final judgement must await more experience with the system

CSL is a machine-based language based on FORTRAN notation and closely follows the original philosophy of the GSP Its main contribution to the art consists of the extensive use of set concepts and cycles (which it shares with SIMSCRIPT) It emphasizes the importance in complex models of control actions based on decisions, which in turn involve complex tests and the test set available has been made very powerful

ESP is a machine-based language, based on Algol, again following the pattern of GSP Its main contribution is the treatment of variables associated with a machine These are assembled with a machine prior to committal (making it disappear) and are stored with the machine and are inaccessible until it becomes available (appears) This gives a set of local variables defined in time rather than by block context, which may prove useful However, the immediate impression is that the inaccessibility of the data when the machine is committed may be a nuisance, especially in complex situations where control is based on the state of the plant This feature has a certain similarity to the pointing features of GSP (q v)

GSP is a language which, although it has had a certain publicity, has only been used extensively by its originating group This largely stems from the implementation only being available on a small non-standard computer

The machine is a two-level machine, and the language reflects this in its matrix notation of cells Each machine has a row of this matrix associated with it and access to this row in the fast store can be achieved by pointing at it with a special statement This also introduces a certain brevity in the language, and the pointing feature will be retained even in the 503 version The 503 is, of course, a single level machine

As would be expected of a long-established language, GSP is probably the most developed language in the facilities it offers both the model writer and the developer and user However, it is a very terse language, being designed for use by mathematically oriented users Indeed, the group which uses it has decided views on the inadvisability of allowing non-mathematical oriented people to work in the simulation field

A unique feature of the language is the facilities offered to enable manually controlled simulation models to be built These models are the industrial counterpart of the logistics gaming systems developed by the RAND Corporation

MONTECODE uses, in contrast to the other languages, an interpreted rather than a compiled program It was implemented on a small slow computer, and, although early in the field, is unlikely to be suitable now for anything except very small models

SIMON is another machine-based Algol language, modelled closely on the ideas of GSP It introduces the set concept and leans heavily on it in its model formulations For simple models this is sometimes rather clumsy, but in complex situations will be powerful

The development facilities are rather primitive, but the language is in an early stage of development itself Similarly, printing facilities are are merely those of the Elliott Algol, on which it is based

Mention must be made of two other languages not based on the event time idea

RSP The Recursive Simulation Program is based on the development of a model of a system using Feller's Concept of a recurrent event and leads to recurrence relations between variables at successive occurrences of the event It gives a rapid method of simulation for simple systems The need for a special language has largely disappeared with the introduction of general algorithmic languages, since the recurrence structure is easily imitated by a scan loop

DYNAMO is a simulation system devised by J W Forrester in connexion with his Industrial Dynamics This is an adaptation of the ideas of Tustin to use servo mechanism theory in economics, applied on the more detailed level of a plant or industry The models consist of a set of differential equations to explain the behaviour of macro-variables

The DYNAMO system enables these equations to be specified, and the computer solves them by a crude Euler approximation [14]

Available computer machinery will determine the appropriate language needed by an administrator However, as previously stated, programs listed in Tocher's Table are available from European and United States sources

Models, definitions, and languages of simulation have been presented The remainder of this chapter will introduce the reader to four cases illustrating simulation processes

[14] K D Tocher, "Review of Simulation Languages," *Operational Research Quarterly* XVI (June, 1965) pp 213–215

Cases

Case 1. Business Model

The American Management Association Business Simulation Game was developed as a result of war games conducted by the armed forces The game, designed in a quantitative fashion, resulted in a mathematical model of a business This set forth formulae that presented the game in cause and effect fashion A realistic approximation of an actual business situation was constructed, yet anyone could profit from playing it The objective was to give players from various levels of management an opportunity to experience the total operation of a business In the final game over twenty key decision areas requiring decisions about production, marketing, research and development, and expansion of production capacity were utilized

The primary goal of the game was to maximize profits over a period of time However, players also evaluated their efficiency over subareas of the total game Each team was required to make a number of decisions about such things as allocation of money, level of production, and price of manufacturing A major contribution of the game rested in the fact that the interrelationships of the various game factors were reasonably and fairly presented to the players of the game

> The game's basic situation it that of a number of firms producing a single item in competition for known consumer market Each firm possesses the following information concerning its position in each stage of the play (1) total sales in units and dollars over the preceding time period, (2) price of the item over the preceding time period, (3) inventory position at the end of the preceding time period, (4) maximum production rate over the next time period and actual production rate over the preceding time period, (5) unit costs of production levels over the next time period, (6) share of the market over the preceding time period, (7) allocation of working capital to marketing research and development and increase in production capacity over the last period, (8) total funds available for allocation during the next period
>
> In addition each firm possesses a certain amount of information concerning its competitors For example, their prices and their total assets On the basis of this information and of past history which players are allowed and encouraged to keep, a number of decisions must be made

governing the play over the next period These involve the determination of (1) price, (2) marketing budget, (3) research and development budget, (4) rate of production, (5) increase or decrease in production capacity

A basic restriction on allocations is that no borrowing is allowed which means that all budgetary allocations must be covered by capital on hand Concerning the effects of these decisions, players are given only the following obvious qualitative market relationships (1) increase in production capacity increases maximum production rate, (2) increase or decrease in actual production rate and production capacity involves a change in unit cost, (3) increase in research and development decreases unit cost and increases attractiveness of product and vice versa, (4) increase in marketing expenditure increases attractiveness of product, (5) increase in price decreases attractiveness of product, (6) attractiveness—which depends upon price, marketing and research and development—determines share of market

The market consists of a known total demand for the item which increases at a certain rate per stage Play continues for a fixed number of stages with each team making the required decisions in an attempt to optimize its position [15]

The mechanics of the game involve a group of executives who are divided into teams or companies, each comprising from three to five persons These companies enter into competition for some hypothetical market The game is divided into time periods of three months each, and the companies usually play from twenty to forty quarters Hence, they simulate up to ten years of competition in this short period of time

Case 2 Boston College Decision-Making Game

The program is designed to interrelate the decisions of three groups of participants managing the production, distribution and financial factors of three firms competing for sales of a single product in four market areas The specific decisions and the limitations imposed by the model are described in a set of Instructions for the Participants in the Boston College Management Decision-Making Exercise The three firms begin operations in relatively equal overall positions, although they have different shares of the market in each of the four areas The model converts the decisions into results which are then reported back to the participants in the form of management reports on costs, sales, operations, cash,

[15] Ricciardi, Frank M , et al *Top Management Decision Simulation* E Marting editor, New York American Management Association, pp 72–73

assets, and liabilities The participants must interpret these results and determine a new set of decisions which will better attain the objectives of the firms The cycle is repeated until the learning outcome of the exercise is achieved

In addition to the decisions of the firms, and their starting position, the program requires a number of variables which reflect the changing business situation, such as Gross National Product, Stock Market Quotations, and Interest Rates Hence, the firms are faced with the uncertainty characteristic of business decision making Because the firms are in competition for the market, actions of one firm affect the condition of the others, so that good decisions depend upon relative performance More importantly, however, the model is designed to avoid rewarding shortrun guesses, and to benefit those firms which establish sound long-run plans and policies Moreover, the model is flexible enough to allow the participants to establish their own objectives, and control their operations in the light of these aims Finally, the model provides for improvements in the product and cost reductions through Research and Development allocations In short, the Decision-Making Exercise program provides a highly flexible top-management decision simulation for the use of groups which are engaged in organized learning [16]

Case 3. Management Decision-Making Laboratory

A mathematical model of a business economy has been designed, within which three companies, selling the same product, compete for their share of the market The formulas used in the model have been incorporated into a 1401 program which is furnished by IBM Before the start of play, the operator uses the program cards to prepare the system tape required in operating the game Next, he prepares the initial reports and cards needed to start, by processing the initial input cards provided for this purpose

After a briefing session, the participants, using the initial reports and other data, manage their firms by deciding unit prices and marketing, plant improvement, production and research expenditures for the coming quarter They enter their decisions on a form which is returned to the data processing center The information is then punched into decision cards which are placed behind the rest of the input deck and entered into the 1401

The 1401 then simulates the business activity during the quarter in

[16] John E Van Tassel and Vincent P Wright, "Boston College Decision Making Exercise," unpublished paper (March, 1962), p 4

accordance with the rules of the model and prepares a series of reports showing the results of the quarter's activity A new set of history cards for use in the next quarter is punched at this time The reports are then forwarded to the participants and the cycle is repeated [17]

Case 4. UCEA Simulation for Administrators

The UCEA simulation materials that developed during the late fifties are situational tests for the purpose of evaluating the development of criteria of success in school administration The materials—which include motion pictures, film strips, tapes, and printed matter—are used to simulate an elementary school and a township

The simulation materials are designed around the principal of the elementary school The administrator "playing the game" is first shown a film strip to acquaint him with the community The first day and a half of the weeks experience is spent in getting acquainted with the community.

After becoming familiar with the community, the principal is given a detailed description of the school system regarding personnel, instruction, funds, facilities, and school community relations Information is also available about faculty meetings, interviews with parents, and classroom work of teachers

Relevant information is available concerning the physical facilities of the building, personnel folders, and staff roster A staff handbook, school board handbook, legal code, census data, test scores, and school events are furnished the principal He also receives tape recordings of parent-teacher conferences, teacher conversations, and school board meetings

The principal, upon assuming the directorship of the school, records a speech for the PTA and writes articles for the local paper and school magazine

After the detailed briefing regarding the community, school, staff and students, the principal is seated at his desk and is confronted with the "in-basket" situation The "in-basket" situation involves various administrative details ordinarily associated with the principalship The details range from routine correspondence to more serious personnel problems The entire situation is designed to create an environment that duplicates a "real" school situation [18]

[17] IBM Reference Manual, No B20-0285, (1963), p 1

[18] "Simulation in Administrative Training," Columbus, Ohio University Council for Educational Administration, 1960, pp 3–5

Summary

This chapter has furnished two models and four cases for the reader to better understand simulation techniques In addition definitions and languages of simulation have been presented These examples illustrate how one can study the interrelatedness of various components without actually operating the complete system

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CHAPTER 9

Statistical Decisions

Introduction

The purpose of this chapter is to introduce a few basic concepts regarding statistical decisions This brief treatment furnishes some understanding of the stochastic or probabilistic basis for statistical decisions A simple mathematical treatment of point and interval estimation is presented A brief treatment of probability, errors, sample size, and applications of the normal curve complete the section

Statistical decision making is a procedure whereby one forms judgments from probabilistic data It is a process that enables one to make decisions under conditions of uncertainty

Consideration of five basic terms should assist in the understanding of statistical decisions These terms are population, parameter, sample, statistic, and randomness

A *population* is any clearly defined set, the members of which possess a common characteristic The population might be all the members of AASA in the United States, the members of AASA in Florida, the members of AASA in Tallahassee, Florida, the members of AASA at Florida State University

The population is the set that one defines as having a given characteristic and the set about which one wishes to make some type of judgment It is not

necessary to include all members of a given set in one's definition of a population, but it is imperative that all members be included in that group about which a judgment is to be made If one is interested in a given characteristic of Florida AASA members, the Florida AASA members define the population

A *parameter* is a true measure of some population characteristic Such a characteristic might be the median age of American high school principals, average years of training of American school superintendents, or the variability of classroom size in American elementary schools If one could measure every member of the population, one would know the true population characteristic measurement or parameter However, because of the large number of members in most populations of interest to administrators, it is seldom possible to measure directly the characteristic of all concerned

When, because of large numbers, it becomes impractical to take measurements on all members of the population, one can estimate the true population measurement by taking measurements on a *sample* of the population A sample is a subset of the population and is assumed to represent the population Any sample measurement should yield (within specified error limits) the same information that could be derived from measurements taken in the total population The sample, therefore, is a model or direct representation of the population

The measurement taken on a sample is an estimate of the population parameter and is called a *statistic* Since a statistic is an estimate of a parameter, it is subject to error As will be seen later, the error, also, is predictable and becomes controllable in the decision making process

Since a sample is assumed to be representative of the population, some assurance is required that such representativeness is indeed the case To furnish assurance, a sample is drawn at *random* "Drawn at random" means every member of the population has an equal opportunity to be drawn For example, if a ball is to be drawn at random from an urn, the assumption is made that every ball in the urn is identical and has an equal opportunity of being chosen The concept of randomness is central to statistical inference Randomness is almost the only assurance that bias has been controlled

Much of the early work on statistical inference was conducted through agricultural experiments For example, consider the investigation of the relative efficacy of three insecticides as shown in the model in Figure 9 1 The areas A, B, and C were treated each by a different insecticide After the spray was completed, dead insects were counted from random spots in each of areas A, B, and C Obviously, one of the assumptions made was that the insects

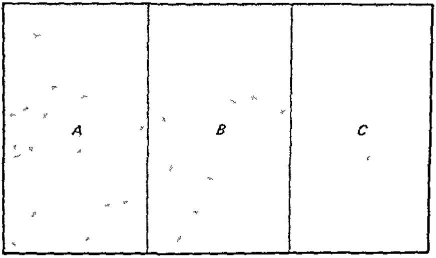


Figure 9.1. *Random plot.*

were randomly distributed throughout the areas. If for some reason the insects tended to cluster in one section of the total plot, the results would be biased. Such a bias was illustrated by the drug-study anecdote that involved testing a new antiseasickness drug. When the impressive results in favor of the new drug were questioned, the investigator elaborated on the soundness of the sample by saying, "I used two clean-cut groups. I gave the experimental drug to the sailors and the control drug to the passengers."

Probability

Mathematical probability is that branch of mathematics concerned with variable data. A commonly used synonym for probability is the term *chance*. Scientific applications of probability have become widespread in physics, biology, medicine, engineering, and chemistry. Fields such as genetics would be nearly nonexistent without mathematical probability. Administrative decisions, which are made under uncertainty almost 100 per cent of the time, are by nature probabilistic.

Consider the Venn Diagram in Figure 9.2. If the total area within the rectangle is N and the total area within the circle is e, the probability of e is defined as the ratio of the area within the circle e to the total area within the rectangle N, that is,

$$P_{(e)} \equiv \frac{e}{N}.$$

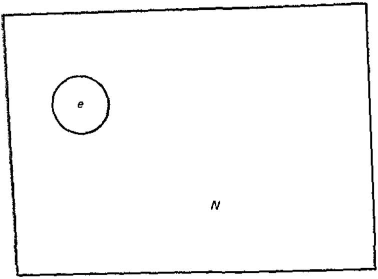


Figure 9.2 *Venn diagram*

An intuitive concept of the meaning of probability might be derived from the following example Assume the area within the rectangle in Figure 9 2 to be a distance from a dart thrower such that every point within the rectangle has an equal opportunity of being hit by a thrown dart Assume further that one hundred darts that are thrown land within the rectangle and five of the one hundred darts land within the circle e If this happens consistently, the chances are five in one hundred that the circle e will be hit if the dart lands within the rectangle If darts are thrown at random and hit the rectangle, the probability is $\frac{1}{20}$ or 0 05 that the circle e will be hit

The Venn diagram in Figure 9 2 illustrates an important characteristic of the probability function As the circle e becomes infinitely small, the ratio e/N tends toward zero and the probability of e tends toward zero As the circle e becomes large but remains within the boundaries of the rectangle N, e loses its circular shape and tends to become identical with the rectangle When e reaches maximum size, it becomes identical in shape with N, and the ratio $e/N = e/N = 1$, that is, $0 \leq P_{(e)} \leq 1$, as $0 \leq e \leq N$, or the probability of e, $P_{(e)}$, varies between 0 and 1 as e varies between 0 and N

From the definition of probability ($P_{(e)} = e/N$), one can formulate other basic concepts of probability functions Consider the Venn diagram in Figure 9 3 Let the total area within the rectangle be represented by N The objective is to determine the probability of a or b being hit if the dart throwing experiment is replicated The solution follows directly from the definition of probability Since the area of the circles a and b is equal to $a + b$ and the

total area within the rectangle is equal to N, the probability of a or b being hit is equal to the ratio of the sum of $a + b$ over N, that is,

$$P_{(a \text{ or } b)} = \frac{a+b}{N}$$

but

$$\frac{a+b}{N} = \frac{a}{N} + \frac{b}{N}$$

and

$$\frac{a}{N} = P_{(a)}, \qquad \frac{b}{N} = P_{(b)}$$

$$P_{(a \text{ or } b)} = \frac{a+b}{N} = \frac{a}{N} + \frac{b}{N} = P_{(a)} + P_{(b)}$$

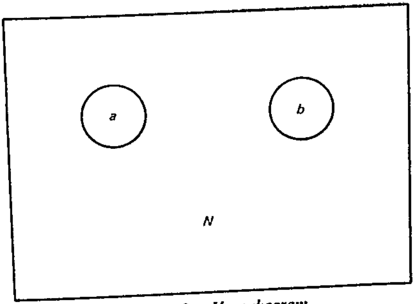


Figure 9.3. *Venn diagram*

Figure 9 3 illustrates the situation where a and b do not overlap Consider the situation illustrated in Figure 9 4 where a and b overlap to the extent c The objective is to determine the probability of c Obviously the probability

of c can best be determined by restricting one's attention to the condition that the total area of interest is now a and b That is, $P_{(c)} = c/b$ or $P_{(c)} = c/a$ This is called conditional probability Problems might occur if c is unknown

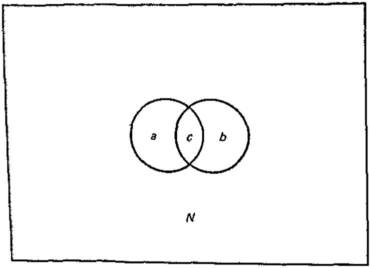


Figure 9 4 *Overlap situation*

Suppose a and b are known From Figure 9 4 it is obvious that the area c includes the overlap area of a and b, that is

$$c = a \text{ and } b$$

and

$$\frac{c}{N} = \frac{a \text{ and } b}{N}$$

but

$$\frac{c}{N} = P_{(c)}, \qquad \frac{a \text{ and } b}{N} = P_{(a \text{ and } b)}$$

$$P_{(c)} = P_{(a \text{ and } b)}$$

However, when dealing with conditional probability, the area of concern is restricted to a and b which includes c

From Figure 9 4 and the definition of probability, the probability of c occurring given that b has occurred $P_{(c \mid b)}$ is equal to the ratio c/b

$$P_{(c \mid b)} = \frac{c}{b}$$

$$= \frac{a \text{ and } b}{b}$$

$$= \frac{\dfrac{a \text{ and } b}{N}}{\dfrac{b}{N}}$$

$$= \frac{P_{(a \text{ and } b)}}{P_{(b)}}.$$

But

$$P_{(c \mid b)} = P_{(a \mid b)}$$

$$P_{(a \mid b)} = \frac{P_{(a \text{ and } b)}}{P_{(b)}}$$

and

$$P_{(a \text{ and } b)} = P_{(a \mid b)} \quad P_{(b)}.$$

If a and b are independent, then

$$P_{(a \mid b)} = P_{(a)}$$

and

$$P_{(a \text{ and } b)} = P_{(a)} \cdot P_{(b)}$$

If overlap occurs as in Figure 9 4 and the objective is to calculate the probability of a or b, ($P_{(a \text{ or } b)}$) the procedure is as follows

$$\frac{a + b - c}{N} = \frac{a}{N} + \frac{b}{N} - \frac{c}{N}$$

$$= P_{(a)} + P_{(b)} - P_{(c)}$$

But

$$P_{(c)} = P_{(a \text{ and } b)}$$

$$P_{(a \text{ or } b)} = P_{(a)} + P_{(b)} - P_{(c)} = P_{(a)} + P_{(b)} - P_{(a \text{ and } b)}$$
$$= P_{(a)} + P_{(b)} - P_{(a)} \; P_{(b)}$$

The reason for subtracting c is evident from the fact that area c is included in area a and again in area b It has to be subtracted once since it is counted twice

Point Estimation

Many administrative decisions involve estimating averages such as salaries, achievement, building costs, personnel characteristics, and expenditures Such averages are used as standards The derivation of one average, the mean, is given below

The objective is to find the point on the fulcrum that will balance the board in Figure 9 5 If the distances between the a's are equal to distances between

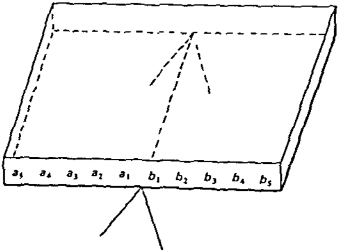


Figure 9.5 *Fulcrum*

the b's, the board should balance because the number of a's is equal to the number of b's

$$(m - a_5) + (m - a_4) + (m - a_3) + (m - a_2) + (m - a_1)$$
$$= (b_5 - m) + (b_4 - m) + (b_3 - m) + (b_2 - m) + (b_1 - m)$$

If m occurs r times on the left side of the equation and s times on the right side of the equation and the a's $= \sum a_i$ and the b's $= \sum b_i$, the equation above can be rewritten as follows

$$rm - \sum a_i = \sum b_i - sm$$

Rearranging terms,

$$rm + sm = \sum a_i + \sum b_i$$
$$m(r + s) = \sum a_i + \sum b_i$$

But

$$r + s = N$$

and

$$\sum a_i + \sum b_i = \sum X_i$$
$$mN = \sum X_i$$
$$m = \frac{\sum X_i}{N}$$

The average is merely the sum of the scores divided by the number of scores

Interval Estimation

The administrator is interested not only in the estimation of averages, but he is interested also in the reliability of his estimates One procedure for making an interval estimation is by taking the sum of the squared deviations of scores from the mean Taking squared deviations assures that the sum will not be zero The derivation follows

Let $\sum x^2 \equiv$ sum of squared deviations

$$\begin{aligned}
\sum x^2 &= \sum (X_i - \bar{X})^2 \\
&= \sum (X_i^2 - 2X_i\bar{X} + \bar{X}^2) \\
&= \sum X_i^2 - 2\sum X_i\bar{X} + n\bar{X}^2 \\
&= \sum X_i^2 - 2n\bar{X}^2 + n\bar{X}^2 \\
&= \sum X_i^2 - n\bar{X}^2 \\
&= \sum X_i^2 - \frac{(\sum X_i)^2}{n}
\end{aligned}$$

$$s^2 = variance = \frac{\sum x^2}{n}$$

$$= \frac{\sum X_i^2 - \frac{(\sum X_i)^2}{n}}{n}$$

$$= \frac{n \sum X_i^2 - (\sum X_i)^2}{n^2}$$

$$s = \frac{1}{n}\sqrt{n \sum X_i^2 - (\sum X_i)^2}$$

If n is small, division by $n - 1$ rather than n (regard sum of squared deviations) will give an unbiased estimate of the standard deviation

Normal Distribution

There are infinitely many distributions or families of curves that can be generated from data However in so far as educational administrators are concerned, most data fit a bell shaped or normally distributed curve as in Figure 9 6

The y axis in Figure 9 6 denotes frequency and the x axis denotes amount The shape of the curve suggests clustering about the average with diminishing

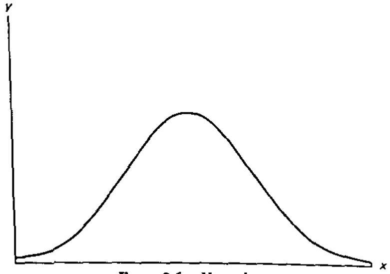


Figure 9 6 *Normal curve*

amounts in the positive and negative directions from the average. The following set of scores from an administrative efficiency test generate a normal curve when plotted.

Table 9.1. Administrative Efficiency Scores

71	75	76	66	73	56	77
80	79	66	85	72	63	67
66	83	76	75	71	71	75
82	72	64	74	74	72	65
62	68	83	68	61	73	74

Table 9.2. Frequency Distribution for Administrative Efficiency Scores

85–89	1
80–84	4
75–79	7
70–74	11
65–69	7
60–64	3
55–59	1

Table 9.3. Administrative Efficiency Scores Curve

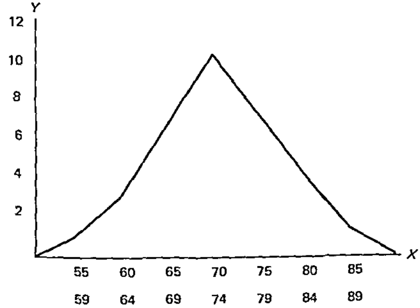


Table 9.1. Area of Normal Curve from Mean to Indicated Deviation from Mean

x/σ	Final digit of x/σ and area									
	0	1	2	3	4	5	6	7	8	9
0	0000	0040	0080	0120	0160	0199	0239	0279	0319	0359
1	0398	0438	0478	0517	0557	5960	0636	0675	0714	0753
2	0793	0832	0871	0910	0948	0987	1026	1064	1103	1141
3	1179	1217	1255	1293	1331	1368	1406	1443	1480	1517
4	1554	1591	1628	1664	1700	1736	1772	1808	1844	1879
5	1915	1950	1985	2019	2054	2088	2123	2123	2190	2224
6	2257	2291	2324	2357	2389	2422	2454	2486	2517	2549
7	2580	2611	2642	2673	2703	2734	2764	2794	2823	2852
8	2881	2910	2939	2967	2995	3023	3051	3078	3016	3133
9	3159	3186	3213	3238	3264	3289	3315	3340	3365	3389
1 0	3413	3438	3461	3485	3508	3531	3554	3577	3599	3621
1 1	3643	3665	3686	3708	3729	3749	3770	3790	3810	3830
1 2	3849	3869	3888	3907	3925	3944	3962	3980	3997	4015
1 3	4032	4049	4066	4082	4099	4115	4131	4147	4162	4177
1 4	4192	4207	4222	4236	4251	4265	4279	4292	4306	4319
1 5	4332	4345	4357	4370	4382	4394	4406	4418	4429	4441
1 6	4452	4463	4474	4484	4495	4505	4515	4525	4535	4545
1 7	4554	4564	4573	4582	4591	4599	4608	4616	4625	4633
1 8	4641	4649	4656	4664	4671	4678	4686	4693	4699	4706
1 9	4713	4719	4726	4732	4738	4744	4750	4756	4761	4767
2.0	4772	4778	4783	4788	4793	4798	4803	4808	4812	4817
2.1	4821	4826	4830	4834	4838	4842	4846	4850	4854	4857
2 2	4861	4864	4868	4871	4875	4878	4881	4884	4887	4890
2 3	4893	4896	4898	4901	4904	4906	4909	4911	4913	4916
2 4	4918	4920	4922	4925	4927	4929	4931	4932	.4934	4936
2.5	4938	4940	4941	4943	4945	4946	4948	4949	4951	4952
2.6	4953	4955	4956	4957	4959	4960	4961	4962	4963	4964
2 7	4965	4966	4967	4968	4969	4970	4971	4972	4973	4974
2 8	4974	4975	4976	4977	4977	4978	4979	4979	4980	4981
2.9	4981	4982	4982	4983	4984	4984	4985	4985	4986	4986
3 0	4987	4987	4987	4988	4988	4989	4989	4989	4990	4990
3 1	4990	4991	4991	4991	4992	4992	4992	4992	4993	4993
3 2	4993	4993	4994	4994	4994	4994	4994	4995	4995	4995
3 3	4995	4995	4995	4996	4996	4996	4996	4996	4996	4997
3 4	4997	4997	4997	4997	4997	4997	4997	4997	4997	4998
3 5	4998	4998	4998	4998	4998	4998	4998	4998	4998	4998
3 6	4998	4998	4999	4999	4999	4999	4999	4999	4999	4999
3 7	4999	4999	4999	4999	4999	4999	4999	4999	4999	4999
3 8	4999	4999	4999	4999	4999	4999	4999	4999	4999	4999
3 9	5000	.5000	5000	5000	5000	5000	5000	5000	5000	5000

Source William Addison Neiswanger, *Elementary Statistical Methods* New York The Macmillan Company 1961, p 713

Note Example of use of above table Between ordinate erected at the mean and one erected 0 59 σ from the mean is included 2224 of the total area.

Using formulae developed earlier in this chapter, the mean and standard deviation of the administrative efficiency scales are found to be 71 3 and 6 6, respectively

Combining the statistics, mean, and standard deviation with Table 9 4, one can make administrative decisions from data rather than guess

Table 9 4 is compiled in terms of *z*-scores, which represent deviations from the mean in standard deviation units as indicated in the formula

$$z = \frac{X - \bar{X}}{s}$$

where X is any score, $\bar{X}$ is the mean of the distribution, s is the standard deviation of the distribution

The mean of the administrative efficiency score being 71 3 and the standard deviation, 6 6, one can determine from Table 9 4 that approximately two thirds of the administrators had scores between 64 7 and 77 9 The limits 64 7 and 77 9 represent one standard deviation above and below the mean, that is 71 3 $\pm$ 6 6 From Table 9 4 one *z*-unit above the mean includes 3413 Since the curve is bilaterally symmetrical, one *z*-unit below the mean also includes 3413 Therefore, one *z* unit above and below the mean includes 6826 or approximately two thirds of the distribution

Standard Error of Mean

The mean is an estimate of a population parameter The estimate is derived from a sample and is subject to error The error is assumed to be random and is predictable in a probability sense The problem is to determine limits within which the mean will fall a given per cent of the time What is needed is a statistic that furnishes information regarding the variability of the mean Such a statistic would seem to be comparable to the variance for the normal distribution Such a variance can be derived as follows

$$V(\bar{X}) = V\left(\frac{1}{n}\sum X\right)$$

$$= \frac{1}{n^2} \quad V(\sum X)$$

$$= \frac{1}{n^2} \quad n \quad V(X)$$

$$= \frac{1}{n} \; V(X)$$

$$= \frac{1}{n} \; \sigma^2$$

and the standard deviation of the mean is

$$\sqrt{V(\overline{X})} = \frac{\sigma}{\sqrt{n}} = \sigma_x$$

Figure 9 7 demonstrates that the mean errors are also normally distributed

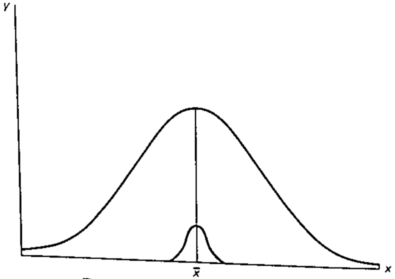


Figure 9 7 *Error distribution of mean*

Assume a mean equal to fifty, a standard deviation equal to fifteen, and the number of cases equal to one hundred What type of decisions can be made regarding the mean? Consider the formula

$$t = \frac{(\overline{X}_i - \overline{X})}{s/\sqrt{n}}$$

in conjunction with Table 9 4 Using the data assumed above,

$$\sigma_{\overline{X}} = \frac{15}{\sqrt{100}} = \frac{15}{10} = 1\ 5$$

Given the above information, what is the probability that the true mean is ≥ 53? First apply the formula

$$t = \frac{(\bar{X}_i - \bar{X})}{s/\sqrt{n}}$$

$$= \frac{53 - 50}{1\ 5}$$

$$= \frac{3}{1\ 5}$$

$$= 2\ 0$$

Since n is large, the table for z can be substituted with the table for t Refer to Table 9 4 to find that 0228 (5000 − 4772) of the curve lies on or above 2 z units The probability is 0228 that the true mean is equal to or greater than 53

The type of decision to be made requires determination of the limits within which the mean will fall a specified number of times per hundred For example, what are the limits which would include the mean 95 per cent of the time? From Table 9 4 one determines that the mean will fall within $\pm 1\ 96$ z units 95 per cent of the time Since z units are normally distributed and mean errors are normally distributed, the same table can be used for both One could infer that the mean would fall within $1\ 96\sigma_x$ units 95 per cent of the time

From Figure 9 8 one sees that the area between the dotted lines contains 95 or 95 per cent of the distribution This is equivalent to $\pm 1\ 96\sigma_x$ Substitute the value 1 5 for σ_x from the above example and use a mean of fifty as before

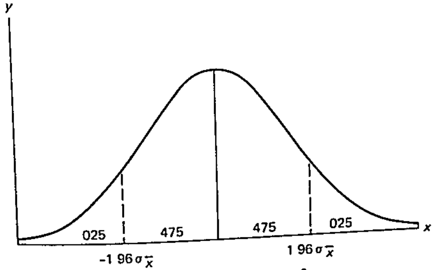


Figure 9 8 *Standard error of mean*

This gives

$$\bar{X} \pm 1\ 96\sigma_x$$

$$50 \pm 1\ 96(1\ 5)$$

$$50 \pm 2\ 94$$

One can conclude from the calculations above that when the probability is 95, the mean will fall within the limits 47 06 and 52 94

Testing Differences Between Means

In the preceding section a discussion was presented regarding the probability that the mean would lie within certain specified limits When an investigation was replicated, the mean fluctuated between the specified limits a given percentage of the time Also, mean errors generated a normal or bell-shaped curve that enabled one to use a table of the areas under the normal curve

When making a statistical inference regarding the difference between two means, one must consider the errors in both means For example, in Figure 9 9, $\bar{x}_1$ might increase to the point *a* or above a certain percentage of the time, but $\bar{x}_2$ might decrease to the point *a* or below a certain percentage of the time Both movements must be taken into consideration

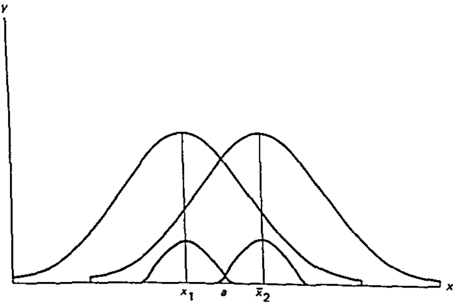


Figure 9 9 *Mean fluctuations*

One could test the likelihood of $\bar{x}_1$ being moved to a or above by the formula

$$t = \frac{a - \bar{x}_1}{s/\sqrt{n}}$$

or by the formula

$$t = \frac{\bar{x}_2 - a}{s/\sqrt{n}}$$

If one wished to test the likelihood that the distance $\bar{x}_2 - \bar{x}_1$ occurred by chance, one should combine the two error terms $s_1/\sqrt{n_1}$ and $s_2/\sqrt{n_2}$ as in the formula

$$t = \frac{\bar{x}_2 - \bar{x}_1}{\sqrt{(s_1/\sqrt{n_1})^2 + (s_2/\sqrt{n_2})^2}}$$

The formula above is the well known student's t-test for finding the significance of the difference between means The logical structure of the t-test should be apparent from the development of the concept of a z-score and the area under the normal curve

This relatively unsophisticated discussion of statistical inference through hypothesis testing furnishes some indication of a systematic method for making decisions For example, if the means $\bar{x}_1$ and $\bar{x}_2$ above represent average scores made by new principals on an objective test, one could determine quantitatively whether or not one method of selection was better than the other

Errors

Reference has been made earlier to the problem of errors When making a statistical inference or testing a statistical hypothesis, two types of errors are possible A Type I error might be committed if the Null hypothesis (that no significant difference exists) is rejected when in fact it is true

Suppose a test is given before and after an in-service workshop for educational administrators Suppose, also, that an objective measurement is made

to determine change on a criterion variable. The Null Hypothesis will state that no significant change takes place. That is, the Null Hypothesis will hold that any change which does take place can be explained on the basis of chance fluctuations.

If the Null Hypothesis is rejected (the assertion that the difference is significant), when in fact it is true, (the difference is not significant) then a Type I error will be committed. The likelihood of committing a Type I error is illustrated in Figure 9.10.

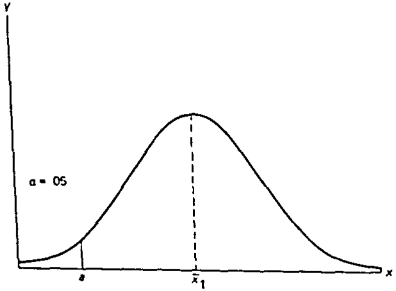


Figure 9.10. *Type I Error—α.*

The point a denotes the limit beyond which lies Alpha α or .05 of the distribution The likelihood of the mean $\bar{x}_1$ following below a is .05. Therefore, if one states that the mean $\bar{x}_1$ is $\geq a$, one could anticipate being correct 95 per cent of the time. Therefore, the likelihood of committing a Type I error would be 05

Another type error, Type II, can occur if the Null Hypothesis is accepted when in fact it is false. Assume the a in Figure 9.11 to be the same point that that is located in Figure 9.10. The probability of $\bar{x}_2$ being β is .10. The concept can be better understood if Figure 9.10 and Figure 9.11 are placed on the same graph as in Figure 9 12.

Figure 9 12 indicates the curves generated from the errors of means $\bar{x}_1$ and $\bar{x}_2$ Let

$$\bar{x}_1 = 20 \qquad \bar{x}_2 = 17$$
$$S_{\bar{x}_1} = 1 \qquad S_{\bar{x}_2} = 1.$$

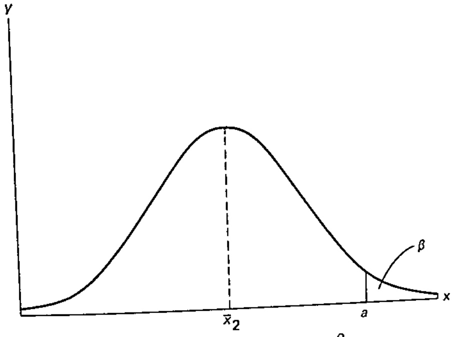


Figure 9.11. *Type II error—β.*

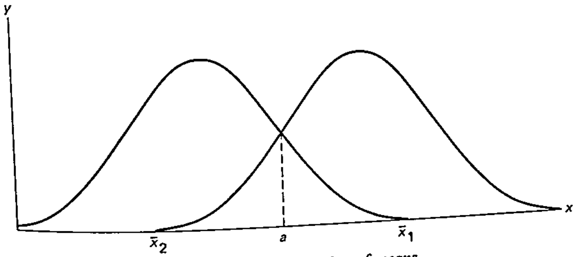


Figure 9.12. *Distribution of means.*

At the point $\alpha = .05$ from Table 9.4, one determines that $z = -1.65$, that is,

$$z = \frac{a - \bar{x}_1}{s/\sqrt{n}} = \frac{a - 20}{1} = -1.65$$

or

$$a - 20 = -1.65$$
$$a = 18.35.$$

From the distribution for $\bar{x}_2$

$$z = \frac{a - \bar{x}_2}{s/\sqrt{n}}$$

$$= \frac{18\ 35 - 17}{1}$$

$$= 18\ 35 - 17$$

$$= 1\ 35$$

From Table 9 4 for z at $z = 1\ 35$ $\beta =\ 09$, the probability of a Type II error is therefore 09 One can also determine the power of the test which is defined as $P = 1 - \beta$ The power of this test would be $1 -\ 09 =\ 91$ The test would discriminate with 91 per cent accuracy

Sample Size

The logic of the discussion above can be applied to decision making about sample size Consider Figure 9 13

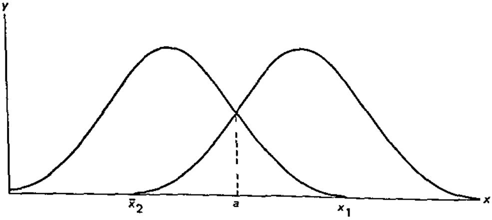


Figure 9 13 *Sample si e*

At

$$\alpha =\ 05 \qquad z = -1\ 65$$

at

$$\beta = .10 \qquad z = 1.28.$$

Assume

$$\bar{x}_1 = 20 \qquad S_{\bar{x}1} = 2$$

$$\bar{x}_2 = 19 \qquad S_{\bar{x}2} = 2.$$

$\bar{x}_2$ and $\bar{x}_1$ denotes means of distributions in 9.12 and 9.13.

Then for $\bar{x}_1$ distribution

$$\frac{a - 20}{2/\sqrt{n}} = -1.65$$

and for $\bar{x}_2$ distribution

$$\frac{a - 19}{2/\sqrt{n}} = 1.28.$$

Subtracting the $\bar{x}_2$ distribution from the $\bar{x}_1$ distribution gives

$$-2.93 = \frac{1}{2/\sqrt{n}} \qquad \text{or} \qquad 5.86 = \sqrt{n}.$$

Therefore, $n \simeq 34$.

One could also use an iterative procedure for determining sample size as follows.

$$t = \frac{\bar{x}_2 - \bar{x}_1}{s/\sqrt{n}}$$

t = value of t-test

$\bar{x}_2 - \bar{x}_1 = D$ = difference to be detected between means

s = standard deviation

$$\therefore \qquad t = \frac{D}{s/\sqrt{n}} = \frac{D\sqrt{n}}{s}$$

or

$$\sqrt{n} = \frac{st}{D}$$

$$n = \frac{s^2 t^2}{D^2}$$

Assume $D = 2$, $s = 5$ For the first approximation of the value of t, assume n to be infinitely large From Table 9 4, $\alpha =$ 05, $t = 1$ 96 Therefore,

$$\sqrt{n} = \frac{1\ 96 \times 5}{2},$$

where $t = 1$ 96, $s = 5$, $D = 2$

$$n = \frac{1\ 96^2 \times 5^2}{2^2}$$

$$n \simeq 24$$

But if $n = 24$ from Table 9 4, $t = 2$ 064 Hence

$$n = \frac{2\ 064^2 \times 5^2}{2^2}, \qquad n \simeq 27$$

But if $n = 27$, then $t = 2$ 052 Hence

$$n = \frac{2\ 052^2 \times 5^2}{2^2}, \qquad n \simeq 26$$

But if $n = 26$, then $t = 2$ 056 Hence

$$n = \frac{2\ 056^2 \times 5^2}{2^2}, \qquad n \simeq 26$$

The iterative procedure is now complete and n apparently is equal to 26

Summary

Most administrative decisions are made under conditions of uncertainty. This chapter has presented some elementary statistical concepts which illustrate the nature of statistical decision making. A review of the basic terminology and concepts of probability have been presented as have methods of estimation and the rationale of errors.

CHAPTER 10

Allocation of Resources

designed to handle the general class of linear programming problems Ordinary high school algebra will be sufficient to solve the problems if the reader will give careful attention to the details of working through the problems

The linear programming method has been applied to a variety of educational problems including optimal school lunch menu planning, school transportation, flexible scheduling, building, space requirements, and a variety of other areas

Introduction to Linear Programming

Definition

Linear programming is a mathematical technique for optimizing the allocation of resources The assumption is made that resources are scarce (or limited) and that the best distribution or mix of available resources is not readily apparent from intuitive sources Therefore, an analytic approach is required to determine the optimal distribution or mix Linear programming is one analytical approach available for finding the optimal allocation of scarce resources

Brief Background

Linear programming is a relatively new technique that has been designed for the solution of allocation problems It belongs under the umbrella term *operations research* Primary creative effort and consequent applications to business, industry, and the military have occurred since World War II Names which have been associated prominently with linear programming include R L Ackoff, E L Arnoff, A Charnes, C W Churchman, W W Cooper, G B Danzig, Leontief, S I Gass, T L Saaty, and S Vajda

The problem involves finding the best arrangement of cell entries in a matrix such as Figure 10 1, which shows that there are given amounts of some product at each row origin Required given amounts of the product are at each column destination The objective is to find the best mix, which will send products from a combination of origins to a combination of destinations Because no origin can satisfy all of the destinations and no destination can handle all of the products, a mix is required The best or optimal mix determination is the objective of linear programming

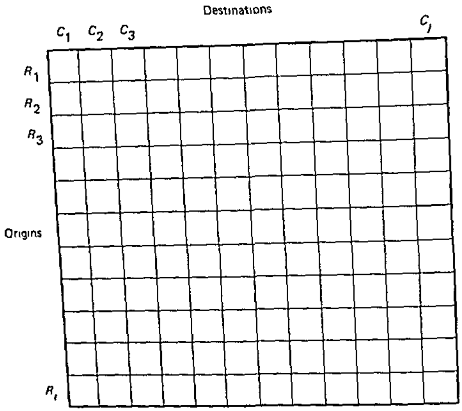


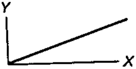
Figure 10 1. *Matrix*

Basic Assumptions

There are three basic assumptions associated with linear programming First, the variables of the problem are non-negative, the variables when expressed in mathematical equations take the form of a straight line The exchange rates are linear Second, the functions are deterministic rather than probabilistic The linear programming model assumes certainty rather than random uncertainty Knowledge must be precise regarding the number of requirements at certain destinations and the number of available items at certain origins These numbers cannot be random in onset and/or arrival Third, there is a unique combination of cell entries that will give the best mix of items moved from origins to destinations

Linear Functions

A function is a set of ordered pairs of number: $F = f(x_i, y_i)$ such that for every x_i there is a corresponding y_i and no two x_i's have the same value For

example,  denotes a function but  does not denote a function The functional concept furnishes a shorthand notation that permits one to determine the value of Y if the value of X is known If it is known that $Y = 2X$, that the value of X be 1, one easily determines Y is equal to 2. If $X = 2$, then $Y = 4$, etc

Definition of Linearity

Linear programming models assume that the equations used are linear A linear function is one in which the independent variable is of the first degree For example, $Y = a + bx$ is a linear equation, $Y = 3 + 4x$ is a linear equation, $Y = 4x^2$ is not a linear equation, $Y = a + bx^3$ is not a linear equation

Figure 10 2 represents the graph of the linear equation $Y = 2 + X$ Table 10 1 furnishes the calculated values

Figure 10 3 represents the graph of the equation $Y = 2X$ Table 10 2 furnishes the calculated values for X and Y

Table 10.1.
Linear Function

X	Y
0	2
1	3
2	4
3	5
n	$n+2$

Table 10.2.
Linear Function

X	Y
0	0
1	2
2	4
3	6
n	$2n$

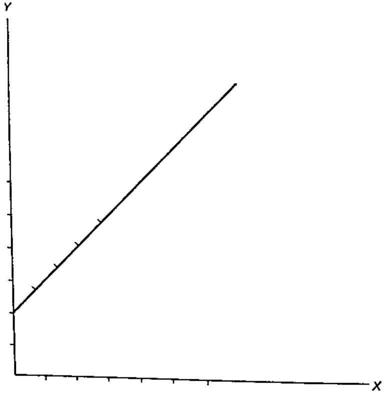


Figure 10.2. $Y = 2 + X$.

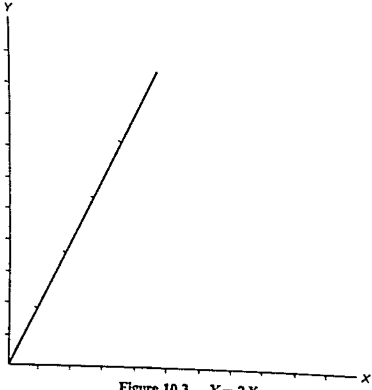


Figure 10.3. $Y = 2X$.

Graph of Nonlinear Equations

The graphs of linear equations have been shown to be straight lines: Hence, the term *linear*. But what about the graphs of nonlinear equations? The following four figures illustrate first, second, third, and fourth degree equations.

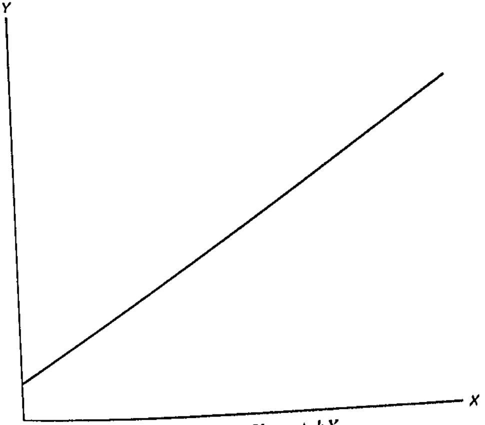


Figure 10.4. $Y = a + bX$.

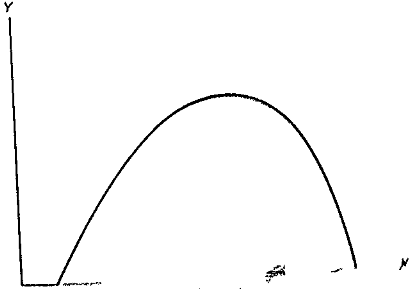


Figure 10.5. $Y = a +$ [illegible]

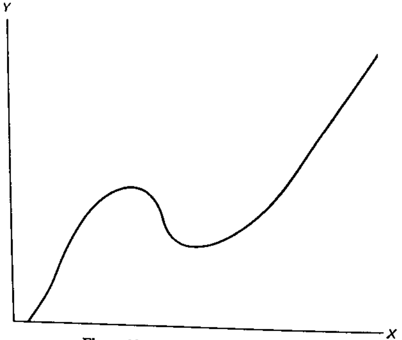


Figure 10.6. $Y = a + bx + cx^2 + dx^3$.

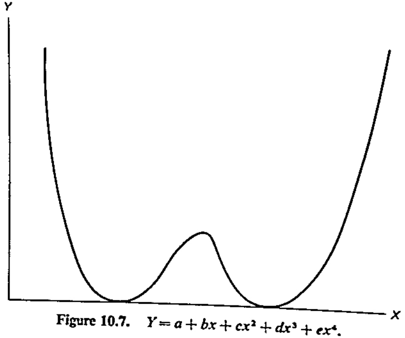


Figure 10.7. $Y = a + bx + cx^2 + dx^3 + ex^4$.

EXAMPLE

Complete a table for $Y = 4 + 2X$
Graph the equation $Y = 4 + 2X$

EXAMPLE

Complete a table for $Y = 2 + X + X^2$
Graph the equation $Y = 2 + X + X^2$

EXAMPLE

Complete a table for $Y = 1 + 2X - X^2 + 2X^3$
Graph the equation $Y = 1 + 2X - X^2 + 2X^3$

EXAMPLE

Complete a table for $Y = 3 + X + X^2 + 2X^3 + X^4$
Graph the equation $Y = 3 + X + X^2 + 2X^3 + X^4$

Linear Inequalities

The equations above all denote functions such that Y is *equal* to some function of X Because linear programming utilizes functions that denote less than or greater than specified amounts, it is necessary to introduce functional *inequalities* Several cases might exist Y might be greater than X, Y might be less than X, Y might be equal to or greater than X, Y might be equal to or less than X Table 1 3 summarizes these possibilities

Table 10.3. Inequalities

$Y \geq X$	Y is equal to or greater than X
$Y > X$	Y is greater than X
$Y \leq X$	Y is equal to or less than X
$Y < X$	Y is less than X

Graph of Linear Inequalities

Figure 10 8 denotes the graph of the inequality $Y < X$ The line in Figure 10 8 represents the function $Y = X$ None of the shaded area touches the line Y is always less than X

Figure 10 9 denotes the graph of the inequality $Y \leq X$ The shaded area in Figure 10 9 includes the line $Y = X$ and all points below the line That is Y is equal to or less than X

Figure 10 10 denotes the graph of the function $Y > X$ No points on the shaded area touch the line $Y = X$ All points are above (are greater than) the line

Figure 10 11 denotes the graph of the function $Y \geq X$ The shaded area covers those points on the line $Y = X$ and all points above that line

Figure 10.8. $Y < X$.

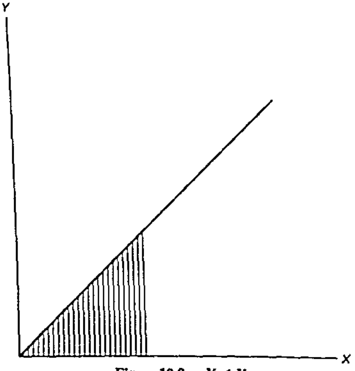


Figure 10.9. $Y \leq X$.

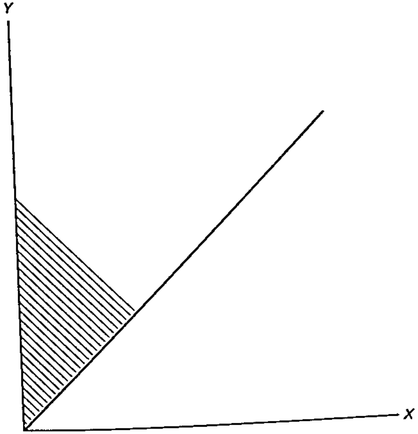


Figure 10.10. $Y > X$.

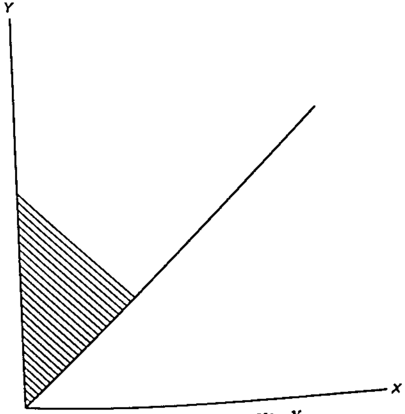


Figure 10.11. $Y \geq X$.

EXAMPLE

Graph the inequality $Y \leq 2 + X$

EXAMPLE

Graph the inequality $Y < 3 + X$

EXAMPLE

Graph the inequality $Y \geq 4 + 2X$

EXAMPLE

Graph the inequality $Y > 3 + 2X$

Finding the Equation for a Straight Line

There are many procedures available for determining the equation for a straight line Below are four common procedures

a Two Points Figure 10 12 denotes the graph of the line $Y = bX$ To

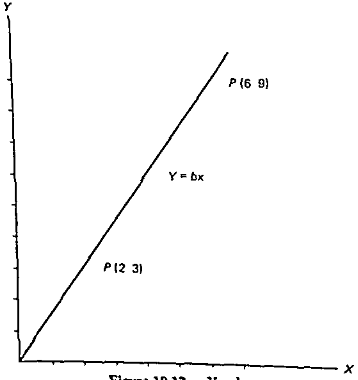


Figure 10 12. $Y = bx$

find b, one applies the formula

$$b = \frac{Y_2 - Y_1}{X_2 - X_1}$$

When

$$Y_2 = 9, \quad Y_1 = 3, \quad X_2 = 6 \quad X_1 =$$

$$b = \frac{9 - 3}{6 - 2}$$

$$= \frac{6}{4}$$

$$= 1\ 5$$

Therefore, $Y = 1\ 5X$

EXAMPLE

Determine the equation for the line in Figure 10 13 using the two points method

b Two Intercepts Consider the information given in Figure 10 14

When

$$X = 0 \Rightarrow Y = 5$$

When

$$Y = 0 \Rightarrow X = 4$$

The equation is of the form

$$AX + BY = C$$

Or dividing by C,

$$\frac{AX}{C} + \frac{BY}{C} = 1$$

set $X = 0$

Then

$$Y = \frac{C}{B} = 5$$

set $Y = 0$

Then

$$X = \frac{C}{A} = 4$$

If $C/A = 4$, then $A/C = 1/4$

If $C/B = 5$, then $B/C = 1/5$ Substitute $(1/4)X + (1/5)Y = 1$ Eliminating fractions, $5X + 4Y = 20$

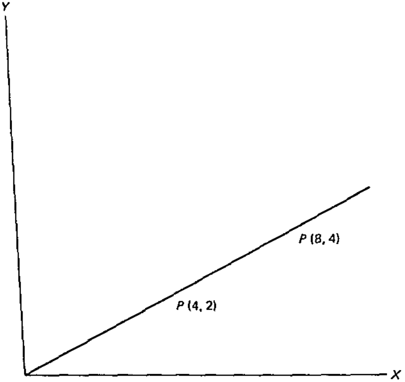


Figure 10.13. *Two-points method.*

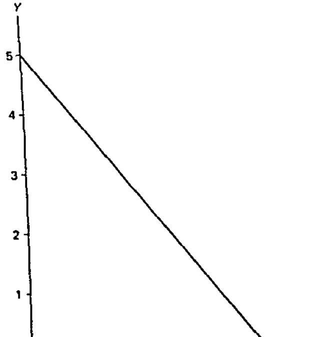


Figure 10.14. *Two intercepts.*

EXAMPLE:

Determine the equation for the line in Figure 10.15 using the two intercepts method.

c. Point and Slope. Consider Figure 10.16.

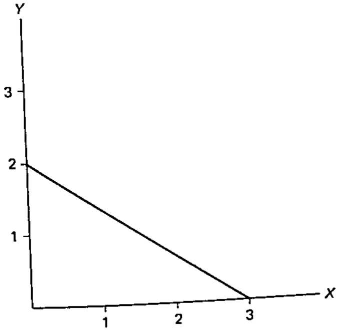


Figure 10.15. *Two intercepts.*

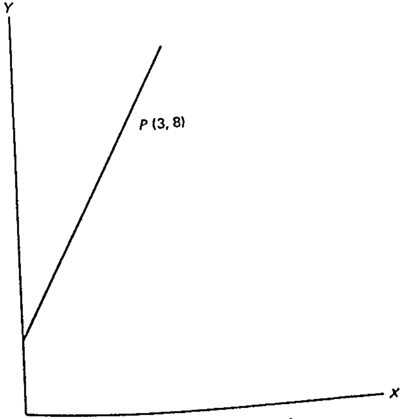


Figure 10.16. *Point and slope.*

Let Slope = 2

$$P_{(3,8)} \Rightarrow X = 3, \qquad Y = 8.$$

The equation for the line is of the form $Y = a + bx$, but at $P_{(3,8)}$ the equation for the line is given by

$$Y = a + bx$$
$$8 = a + 2 \times 3$$
$$8 = a + 6$$
$$a = 2.$$

The equation for the line is $Y = 2 + 2X$.

EXAMPLE:

Determine the equation for the line in Figure 10 17

$$b = .5$$
$$y = 5, \qquad x = 4$$

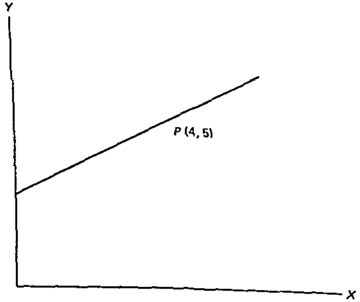


Figure 10.17. *Point and slope.*

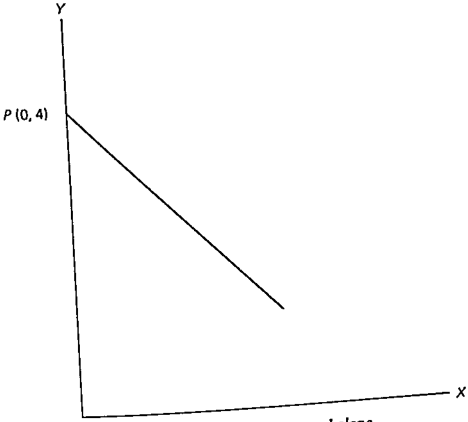


Figure 10.18. *Intercept and slope.*

d. Intercept and Slope. Consider the line given in Figure 10.18.

$$\text{Intercept} = 4$$
$$\text{Slope} = -1$$

The equation is of the form

$$Y = a - x$$

at

$$x = 0, \qquad y = 4$$
$$4 = a - 0$$
$$4 = a.$$

Hence:

$$Y = 4 - x.$$

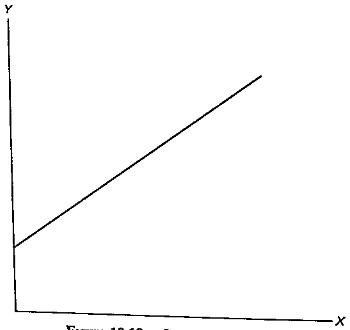


Figure 10 19 *Intercept and slope*

EXAMPLE

Determine the equation for the line in Figure 10 19 using the intercept and slope method

$$\text{Intercept} = (0\ \ 1)$$

$$\text{Slope} \quad = 7$$

Intersection of Two Lines

The intersection of lines plays an important role in the graphic solution of linear programming problems Hence two methods are given for finding the intersection of two lines

a Elimination Assume the equations for two lines are given by

(a) $$2x + 3y = 6$$

(b) $$x - 2y = 4$$

The coefficients for x can be made equivalent by multiplying equation (b) by 2

(a) $$2x + 3y = 6$$

(b) $$2x - 4y = 8$$

Subtracting (b) from (a) gives

$$7y = -2$$

$$y = -\frac{2}{7}$$

Substituting back into the original equation (b)

$$x - 2\left(-\frac{2}{7}\right) = 4$$

$$x + \frac{4}{7} = 4$$

$$x = 4 - \frac{4}{7} = \frac{24}{7}$$

The lines (a) and (b) intercept at the point

$$P\left(\frac{24}{7}, -\frac{2}{7}\right)$$

that is, the lines intersect at $x = 24/7$ and $y = -2/7$

b Substitution Assume the equations for (a) and (b) to be the same as given above

(a) $$2x + 3y = 6$$

(b) $$x - 2y = 4$$

From equation (b) one determines that $x = 4 + 2y$

Substituting that value for x in (a) gives

$$2(4 + 2y) + 3y = 6$$

$$8 + 4y + 3y = 6$$

$$7y = -2$$

$$y = -\frac{2}{7}$$

Substituting $y = -2/7$ in equation (b) gives

$$x - 2\left(-\frac{2}{7}\right) = 4$$

$$x + \frac{4}{7} = 4$$

$$x = 4 - \frac{4}{7} = \frac{24}{7}$$

The point of intersection is

$$P\left(\frac{24}{7}, -\frac{2}{7}\right)$$

as above

EXAMPLE

Determine the point of intersection of the two lines (a) and (b) by the elimination method

(a) $$3x + 2y = 7$$

(b) $$x - 3y = 6$$

EXAMPLE

Determine the point of intersection of the two lines a and b by the substitution method

(a) $$3x + 2y = 7$$

(b) $$x - 3y = 6$$

Solutions to Linear Programming Problems

Three methods of solution will be described to illustrate the solution to linear programming problems graphic method, transportation method and simplex method

First, there are some general procedures to be followed before any solution can be attempted A series of steps follows which will serve as a guide for prob lem manipulations

Step 1 Outline the problem
Step 2 Determine the constraints
Step 3 Set up equations
Step 4 Make sure that the assumptions of linearity and certainty are fulfilled
Step 5 Set up the objective function
Step 6 Determine the optimal solution
Step 7 Reconcile quantitative and qualitative aspects of problems

Graphic Method

PROBLEM

Step 1 Assume that a superintendent needs to make a decision regarding the allocation of resources for equipment E and personnel P for three educational functions science, driver training and vocational education
The return on dollars invested differs for equipment and personnel The superintendent's objective is to maximize the return on expenditures

Step 2 Assume that there are (a) forty hours per month available for science for each science student, (b) thirty hours available for each driver education student and (c) forty-five hours available for each vocational education student The science student requires one hour work per science unit if equipment is used and four tenths hour per unit if personnel are used The driver education student requires six tenths hour per unit if equipment is used and five tenths hour per unit if personnel are used The vocational education student requires five tenths hour for equipment and nine tenths for personnel

The information above can be summarized in Table 10 4

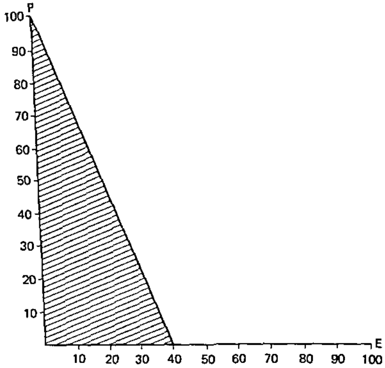


Figure 10.20. *Graph of* $1.0E + .4P \leq 40$.

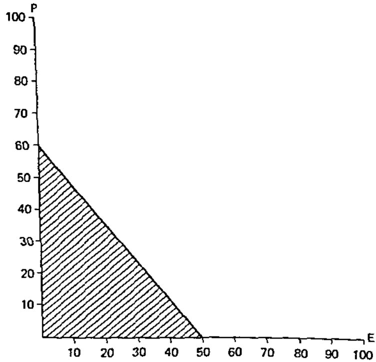


Figure 10.21. *Graph of* $.6E + .5P \leq 30$.

Table 10.4. Constraints and Requirements

	Science	Driver Education	Vocational Education
Equipment	1.0	.6	.5
Personnel	.4	.5	.9
Availability	40.0	30.0	45.0

Step 3. From Table 10.4

$$1.0E + .4P \leq 40$$

$$.6E + .5P \leq 30$$

$$.5E + .9P \leq 45.$$

Step 4. Functions are linear and certain.

Step 5. Assume that the return on dollars spent for personnel is ten and the return on dollars spent for equipment is eight. Then the objective function to be maximized is

$$0_{\max} = 10P + 8E.$$

Step 6. In order to determine the optimal solution when using the graphic method, it is necessary to set up a polygon as follows.

Putting Figures 10.20, 10.21, and 10.22 together gives Figure 10.23, the solution polygon.

Any point within the shaded area of Figure 10.23 is a solution to the problem. That is, it fulfills the requirements of the problem and does not violate any constraints. The optimal solution will be found at one of the vertices. Therefore, the graphic solution involves trying, (by trial and error) each vertex to find the maximum return.

The values for E and P are given below. They have been derived directly from Figure 10.23.

(a) (0, 0).

(b) (0, 50).

(c) (15.7, 41.3).

(d) (30.8, 23.0).

(e) (40, 0).

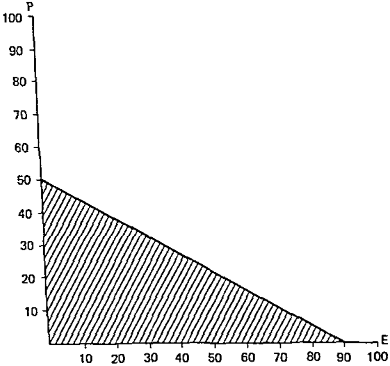


Figure 10.22. *Graph of* $5E + .9P \leq 45$

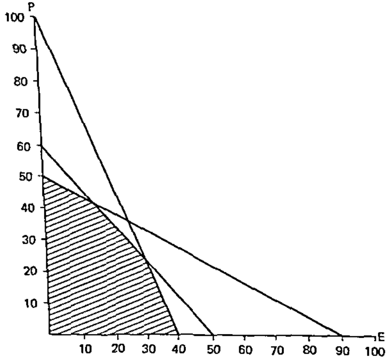


Figure 10.23. *Solution polygon.*

Multiplying the expected returns for E and P by the values at each vertex gives the following:

(a) $0 \times 10 + 0 \times 8 = 0$.

(b) $0 \times 10 + 50 \times 8 = 400$.

(c) $15.7 \times 10 + 41.3 \times 8 = 487.4$.

(d) $30.8 \times 10 + 23.0 \times 8 = 492.0$.

(e) $40 \times 10 + 0 \times 8 = 400$.

The maximum return occurs at (c) 492.0.

The decision should be made to have the students spend fifteen and seven tenths (15.7) hours per month on activities with equipment and forty-one hours per month on activities with personnel.

Transportation Method

The transportation method assumes (a) a linear relationship, (b) certainty and (c) a one-to-one exchange rate.

The transportation method can best be explained by an example. Assume that in a given situation there are 150 students (S_i) consisting of three types and five teachers (T_j) each of a different type. Assume further the distribution of teachers and students as follows:

$$
\begin{aligned}
S_1 &= 30 \\
S_2 &= 75 \\
S_3 &= 45 \\
T_1 &= 15 \\
T_2 &= 25 \\
T_3 &= 35 \\
T_4 &= 40 \\
T_5 &= 35.
\end{aligned}
$$

Each teacher is to be assigned students as above and there are thirty students of type S_1, seventy-five of type S_2, and forty-five of type S_3.

Let Table 10.5 represent the information give above.

Table 10.5.
Student-Teacher Mix

	T_1	T_2	T_3	T_4	T_5	
S_1						30
S_2						75
S_3						45
	15	25	35	40	35	

The objective of the linear programming manipulations is to assign each student in such a way that all constraints will be met Each of the 150 students must be assigned appropriately to each teacher

Let Table 10 6 represent an efficiency matrix where each e_{ij} denotes a normalized efficiency index such that e is equal to or greater than zero and equal to or less than one, that is, $0 \leq e \leq 1$ The e_{ij} denotes the cell where teacher and student intersect, for example, e_{23} denotes the assignment of student of type $2(S_2)$ with teacher of type $3(T_3)$

Table 10.6. Student-Teacher Efficiency Ratios

	T_1	T_2	T_3	T_4	T_5
S_1	1	9	3	4	5
S_2	8	6	2	1	5
S_3	4	3	8	9	1

Table 10 6 adds an additional aspect to the problem In addition to fulfilling the restraints of Table 10 5, Table 10 6 furnishes an efficiency index which associates certain students with certain teachers If X_{ij} denotes the ith student assigned to the jth teacher and if e_{ij} is an efficiency index relating the ith student and jth teacher, the objective of the linear programming model is to maximize the sum of products for efficiency and students

That is, $\sum e_{ij} X_{ij}$ is a maximum The term $\sum e_{ij} X_{ij}$ may require elaboration Reference to Table 10 5 suggests many arrangements of teacher-student mix that would fulfill the given constraints However, when one considers the assignment to cells in such fashion that a maximum number is achieved when each student assignment cell is multiplied by the corresponding efficiency cell, there is a unique assignment which will achieve that maximum

Two methods for solving the transportation problem are given. The first uses the so-called northwest corner rule. The second uses a trial error method. Both procedures are iterative in the sense that an original solution is found and then closer and closer approximations are made until an optimal solution is found.

Northwest Corner Rule

Consider the simple problem in Table 10.7.

Table 10.7. Constraints Matrix

			150
			250
			200
100	200	300	600

The steps for solving the transportation problem follow:

Step 1. Start in the northwest corner cell of the constraints table.
Step 2. Compare the sums of the row and column for which the northwest corner cell intersects.
Step 3. Enter the lesser of the two sums in the northwest corner cell.
Step 4. Proceed to the next cell in the direction of the greater of the two sums and add the amount required to complete the sum in that row (or column). Note: Be sure that no sum in either row or column is exceeded.
Step 5. Proceed to the next cell in the direction which a row or column sum has not been reached.
Step 6. Add the amount required to complete the sum in the row (or column).
Step 7. Proceed in this fashion through the remainder of the table.
Step 8. Recheck the sums of rows and columns to be sure that no constraint has been exceeded.

This completes the first feasible solution and the summary information is given in Table 10.8.

Table 10.8. First Feasible Solution

100	50		150
	150	100	250
		200	200
100	200	300	600

For the data associated with Table 10 8 no sums of rows and columns were equal at the place of intersection This is not always the case The rationale is the same, however, and one proceeds through the table from upper left to lower right as in the example above Applying the procedure given above to the teacher-student problem results in Table 10 9

Table 10.9. Teacher-Pupil Solution

	T_1	T_2	T_3	T_4	T_5	
S_1	15	15				30
S_2		10	35	30		75
S_3				10	35	45
	15	25	35	40	35	

Next test the solution in Table 10 9 for optimality That is, test $\sum e_{ij} X_{ij}$ for a maximum

Multiply the number in the cells of Table 10 9 times the e_{ij}'s in the appropriate cells in the matrix of Table 10 9

$$\sum e_{ij} X_{ij} = 15 \times 1 + 15 \times 9 + 10 \times 6 + 35 \times 2 + 30 \times 1 + 10 \times 9 + 35 \times 1 = 43\ 5$$

Is the sum of products $\sum e_{ij} X_{ij} = 43\ 5$ a maximum? To answer this question one must proceed through an iterative routine until the optimal solution is found

A high sum of products is desirable Therefore, transforming numbers within cells might improve the sum of products For example, sending the students from S_1T_1 to S_1T_2, and so forth, changes the total from 43 5 to 89 5 and the constraints remain fulfilled Table 10 10 shows these changes

Table 10.10. Optimal Solution

	T_1	T_2	T_3	T_4	T_5	
S_1		25			5	30
S_2	15			30	30	75
S_3			35	10		45
	15	25	35	40	35	

Additional change could be made but no increase in the sum of products would be found Therefore, Table 10 10 represents the optimal solution

Trial-and-Error Method

Consider the example in Table 10 5 and Table 10 6 As above a few basic steps are given for computational purposes

Step 1 For column one in Table 10 5 find the cell with the largest e_{ij} in the corresponding column in Table 10 6
Step 2 Enter the maximum number to that cell
Step 3 Proceed to column 2, 3, n as in Table 10 11

Table 10.11. Invalid Solution

	T_1	T_2	T_3	T_4	T_5	
S_1		25				30
S_2	15				35	75
S_3			35	40		45
	15	25	35	40	35	

Table 10 11 indicates that the constraints have not been fulfilled That is, S_2 has been assigned 50 rather than 75 and S_3 has been assigned 75 rather than 45 Therefore, further iteration is necessary Transferring the 30 from S_3T_3 to S_2T_3 and 5 of the 35 in S_2T_5 to S_1T_5 gives the optimal solution as above in Table 10 10

Attention should be called to the fact that there are systematic search procedures for evaluating empty cells and testing for degeneracy The reader will find an excellent treatment of such in R Stansbury Stockton, *Introduction to Linear Programming*, Boston. Allyn & Bacon, 1963, pp 82-104

Simplex Method

The simplex method is the general linear programming model and is applicable to all problems that meet the requirements of certainty and linearity As indicated earlier, linear programming is a search technique It is an iterative procedure that seeks an optimal solution to a mix problem through systematic evaluation of a simplex table

The simplex method generates a set of data that reflects a feasible solution to the problem At the end of each feasible solution, a decision is made regarding whether or not the solution is optimal If the solution is optimal, the routine is finished If the solution is not optimal, another iterative run is made The program continues in this fashion until either an optimal solution is found or until no solution is found Figure 10 24 is a flow chart of the maximizing procedure followed in the simplex solution of a linear programming problem

A verbal description of the flow chart in Figure 10 24 follows

(1) Read the initial simplex table for a basic feasible solution from punched cards

(2) Determine whether there is a positive $C_j - Z_j$ element in the table If there is a positive $C_j - Z_j$ element in the table (indicating that an optimum solution has not been reached), go to Step 3 If there is not a positive $C_j - Z_j$ element in the table (indicating that an optimum solution has been found), go to Step 10

(3) Determine which variable to introduce into the solution, that is, the variable with the most positive $C_j - Z_j$ element

(4) Determine whether the variable to be introduced into the solution has at least one positive exchange coefficient If it does have one or more positive exchange coefficients (indicating that the problem *may* have an optimum solution), go to Step 6 If it does not have a positive exchange coefficient (indicating that the problem does not have an optimum solution), go to Step 5

(5) Print a statement indicating that no optimum solution exists and halt

(6) Determine whether there is more than one "most limiting" restriction on the variable to be introduced into the solution If there is a unique most limiting restriction (indicating that the solution is not degenerate), go to Step 7 If there is not a unique most limiting restriction (indicating degeneracy), go to Step 8

(7) Remove from the solution the variable that imposed the most limiting restriction on the quantity of the new variable being introduced into the solution This variable was determined in Step 6

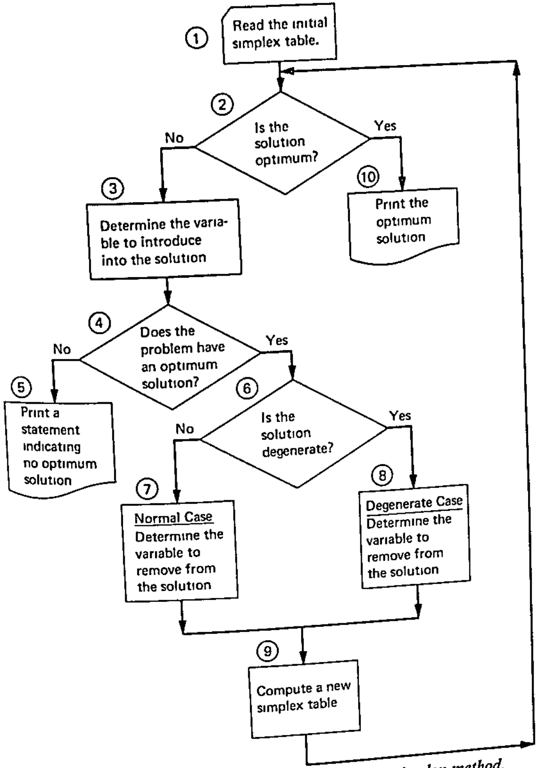


Figure 10.24. *A general block diagram for the simplex method.*

(8) Use the degeneracy procedure to determine which variable should be removed from the solution.

(9) Construct a new simplex table reflecting the changes that have been made in the solution.

(10) Print the final optimum solution and halt.[1]

[1] Thomas H. Naylor and Eugene T. Byrne. *Linear Programming*. Belmont, Calif.: Wadsworth Publishing Company, 1963, pp. 114–115.

The flow chart and procedure are essentially the same as that employed in this chapter The block diagram illustrates quite well the continuous loop which is employed by the program as it seeks better and better solutions until the optimal solution is found The following example is given to illustrate the steps of the simplex procedure

EXAMPLE

A given school cafeteria can accommodate up to 810 students at one time [2] Two lunchroom tables are to be made One, Table A, has a capacity of eighteen, the other, Table B, has a capacity of nine There are 3,500 feet of donated material available Table A requires seventy feet, and Table B requires fifty feet There are 560 labor hours available Because of cutting time it takes eight hours of labor to produce Table A and ten hours of labor to produce Table B Painting and drying require equal time, ten hours The facilities allow for 600 hours of painting and drying By making the tables in the school shop, twenty dollars per table can be saved with A and fifteen dollars with B The decision to be made involves the number of type A tables and the number of type B tables to be made That is, what combination of tables should be made to maximize the savings?

Table 10.12. Constraints and Requirements

	Size	Painting	Labor	Materials	Contribution
A	18	10	8	70	20
B	9	10	10	50	15
	810	600	560	3500	

Inequalities derived for Table 10 12 are

Size	$18A + 9B \leq 810$
Painting	$10A + 10B \leq 600$
Labor	$8A + 10B \leq 560$
Materials	$70A + 50B \leq 3500$

Graphing the above inequalities gives the polygon shown in Figure 10 25 The inequalities of Table 10 12 can be converted to equalities by adding slack

[2] Appreciation is extended to Mr Erskine Murray for suggesting this case study

variables for each constraint Slack variables make no contribution to the objective function and consume no resources The new set of equations follow

$$18A + 9B + S_s = 810$$
$$10A + 10B + S_p = 600$$
$$8A + 10B + S_1 = 560$$
$$70A + 50B + S_m = 3500$$

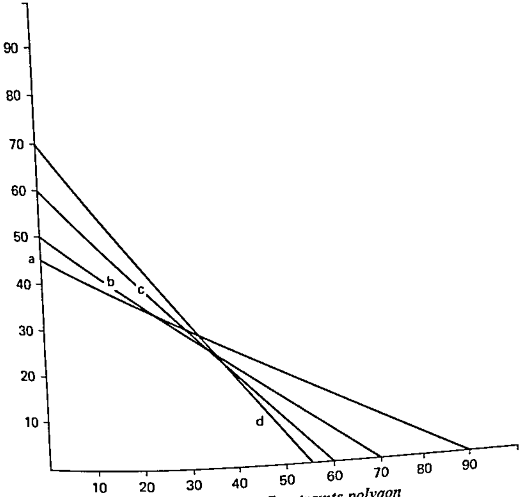


Figure 10.25. *Constraints polygon*

Table 10 13 presents in summary form the information from Table 10 12 with the additional information regarding the slack variables

Table 10.13. Constraints and Slack Variables

	A	B	S_s	S_p	S_1	S_m	Capacity
Size	18	9	1	0	0	0	810
Painting	10	10	0	1	0	0	600
Labor	8	10	0	0	1	0	560
Materials	70	50	0	0	0	1	3500

The simplex method uses the data from Table 10 13 as a basis for computation The step-by-step procedure that follows is patterned after Churchman, et al [3]

Table 10.14. First Feasible Solution

C_i/C_j			0	0	0	0	20 00	15 00
	BASIS	$P0$	$P3$	$P4$	$P5$	$P6$	$P1$	$P2$
0	S(3)	810 0	1 000	0	0	0	18 000	9 000
0	S(4)	600 0	0	1 000	0	0	10 000	10 000
0	S(5)	560 0	0	0	1 000	0	8 000	10 000
0	S(6)	3500 0	0	0	0	1 000	70 000	50 000
	Z_j	0	0	0	0	0	0	0
	$Z_j - C_j$	0	0	0	0	0	−20 000	−15 000

Table 10 14 denotes the origin solution, it has been derived from Table 10 13 Some rearrangement of columns has been made Two additional columns (C_i and basis) and three additional rows (C_j, Z_j, and $Z_j - C_j$) have been added The C_j row denotes original variable contribution, Table A (P_1) contributes $20 and Table B ($P_2$) contributes $15

The C_i column denotes the solution variable contributions Table 10 14 is the origin solution It contains only slack variable that contribute nothing Therefore, all C_i's in Table 10 14 are zero Values for the Z_j row are found by the formula $Z_j = \sum_i C_i X_{ij}$ where C_i is defined as above and X_{ij} denotes the element in the ith row and jth column All of the C_i's in Table 10 14 are zero Therefore, all of the Z_j's are also zero The $Z_j - C_j$ term is found by subtracting the appropriate Z_j from its corresponding C_j

The basis column denotes the variables that are in the solution Since Table 10 14 is the origin solution and contains only slack variables, these variables are listed in the basis column as $B(3)$, $S(4)$, $S(5)$, and $S(6)$ Inspection of the $Z_j - C_j$ row furnishes information regarding possible additional computation

If any $Z_j - C_j < 0$, either the maximum is infinitely large or an optimal solution has not yet been found If all $X_{ij} \leq 0$ in the column for which $Z_j - C_j < 0$, the maximum is infinitely large If some $X_{ij} > 0$, an optimal solution has not yet been found and further interactions are necessary

If all $Z_j - C_j \geq 0$, an optimal solution has been found

If some $Z_j - C_j < 0$ and some $X_{ij} > 0$, one proceeds through an iterative procedure as follows

[3] C. West Churchman, Russell L. Ackoff, and E Leonard Arnoff *Introduction to Operations Research* New York John Wiley & Sons, 1957, pp 304–316

Find the most negative $Z_j - C_j$ value and use that information to replace one of the vectors under the basis column The particular vector to be replaced is determined by finding the minimum ratio when each X_{ij} in the capacity column is divided by the X_{rk} element If k denotes the row "Coming in" and r denotes the row "going out," the replacement row will be found by determining the minimum value of the ratio

$$\text{Min}\ \frac{X_{io}}{Xik}$$

New values for the *replaced* vector can be found as follows

$$X'_{ij} = \frac{X_{rj}}{X_{rk}}$$

Other elements of the new matrix are computed by

$$X'_{ij} = X_{ij} - \left(\frac{X_{rj}}{X_{rk}}\right) X_{ik}$$

Also for the new $Z_j - C_j$

$$(Z_j - C_j)' = (Z_j - C_j) - \left(\frac{X_{rj}}{X_{rk}}\right)(Z_r - C_r)$$

Table 10 15 denotes the (a) solution in Figure 10 25

Table 10.15. Second Feasible Solution

C_i/C_j			0	0	0	0	20 00	15 00
	BASIS	$P0$	$P3$	$P4$	$P5$	$P6$	$P1$	$P2$
20 00	$X(1)$	45 0	056	0	0	0	1 000	500
0	$S(4)$	150 0	− 556	1 000	0	0	0	5 000
0	$S(5)$	200 0	− 556	0	1	0	0	5 000
0	$S(6)$	350 0	−3 889	0	0	1 000	0	15 000
	Z_j	900 0	1 120	0	0	0	20 000	10 000
	$Z_j - C_j$	900 0	1 120	0	0	0	0	−5 000

Table 10 15 is derived from Table 10 14 by the procedure above The most negative $Z_j - C_j$ in Table 10 14 is -20 Find the minimum of the basis ratios

$$
\begin{array}{ll}
S_{(3)} & 810/18 = 45 \\
S_{(4)} & 600/10 = 60 \\
S_{(5)} & 560/8 = 70 \\
S_{(6)} & 3500/70 = 50.
\end{array}
$$

The minimum $S_{(n)} = S_{(3)} = 45$ Therefore, $S_{(3)}$ is to be replaced by $P_{(1)}$ (which contained -20) The X_{ij} values are found by the ratios 810/18, 1 0/18, 0/18, 0/18, 18/18, and 9/18 The old and new values are given below

$$
\begin{array}{rcl}
810 & \Rightarrow & 45 \\
1 & \Rightarrow & 056 \\
0 & \Rightarrow & 0 \\
0 & \Rightarrow & 0 \\
0 & \Rightarrow & 0 \\
18 & \Rightarrow & 1 \\
9 & \Rightarrow & 5
\end{array}
$$

Values for the other elements (X_{ij}) and ($Z_j - C_j$) are found from the formulae above

EXAMPLE

For new value in $S_{(4)}$, $P_{(0)}$

$$X'_{ij} = 600 - \frac{810}{18} 10 = 600 - 450 = 150$$

EXAMPLE

For new value of Z for $P_{(0)}$

$$(Z_j - C_j)' = 0 - \left(\frac{810}{18}\right)(-20) = \frac{16{,}200}{18} = 900$$

Table 10 16 denotes the (b) solution in Figure 10 25

The X_{ij} elements were found as those in Table 10 15 Table 10 17 denotes the (C) solution in Figure 10 25

Table 10 18 furnishes the summary data

Table 10.16. Third Feasible Solution

C_i/C_j	BASIS	$P\,0$	0 $P\,3$	0 $P\,4$	0 $P\,5$	0 $P\,6$	20 00 $P\,1$	15 00 $P\,2$
20 00	$X(1)$	33 3	185	0	0	− 033	1 000	0
0	$S(4)$	33 3	741	1 000	0	− 333	0	0
0	$S(5)$	60 0	1 111	0	1 000	− 400	0	0
15 00	$X(2)$	23 3	− 259	0	0	066	0	1 000
	Z_j	1015 5	− 185	0	0	330	20 000	15 000
	$Z_j - C_j$	1015 5	− 185	0	0	330	0	0

Table 10.17. Optimal Solution

C_i/C_j	BASIS	$P\,0$	0 $P\,3$	0 $P\,5$	0 $P\,5$	0 $P\,6$	20 00 $P\,1$	15 00 $P\,2$
10 00	$X(1)$	25 0	0	− 250	0	050	1 000	0
0	$S(3)$	45 0	1 000	1 350	0	− 450	0	0
0	$S(5)$	10 0	0	−1 500	1 000	100	0	0
15 00	$X(2)$	35 0	0	350	0	− 050	0	1 000
	Z_j	1025 0	0	250	0	250	20 000	15 000
	$Z_j - C_j$	1025 0	0	250	0	250	0	0

Table 10.18. Final Solution

$X(1) = 25\ 00000$
$S(3) = 45\ 00000$
$S(5) = 10\ 00000$
$X(2) = 35\ 00000$

OBJECTIVE FUNCTION (MAX) = 1025 00000

The maximum contribution of the two tables is seen to be $1,025 00 Twenty five A tables $X(1)$ should be made and thirty-five B tables $X(2)$ should be made The other two variables $S_{(3)}$ and $S_{(5)}$ are slack variables and hence contribute nothing to the objective function

Summary

A brief introduction to some applications of linear programming for solving allocation problems has been presented The objective of this chapter has been to introduce the reader to a quantitative approach for making decisions relative to allocation problems No attempt has been made to be either definitive in terms of calculations or adequate in the treatment of the theoretical foundations of linear programming Adequate references are listed for the interested reader to explore both theory and practice in greater depth

A brief treatment of a specific quantitative method is designed to suggest the applications of this technology to administrative decision making rather than to emphasize the technology per se

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